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Nuclear Power

REACTORS · MATERIALS · INSTRUMENTATION · PROCESSES · IRRADIATION

The UK's first five stations

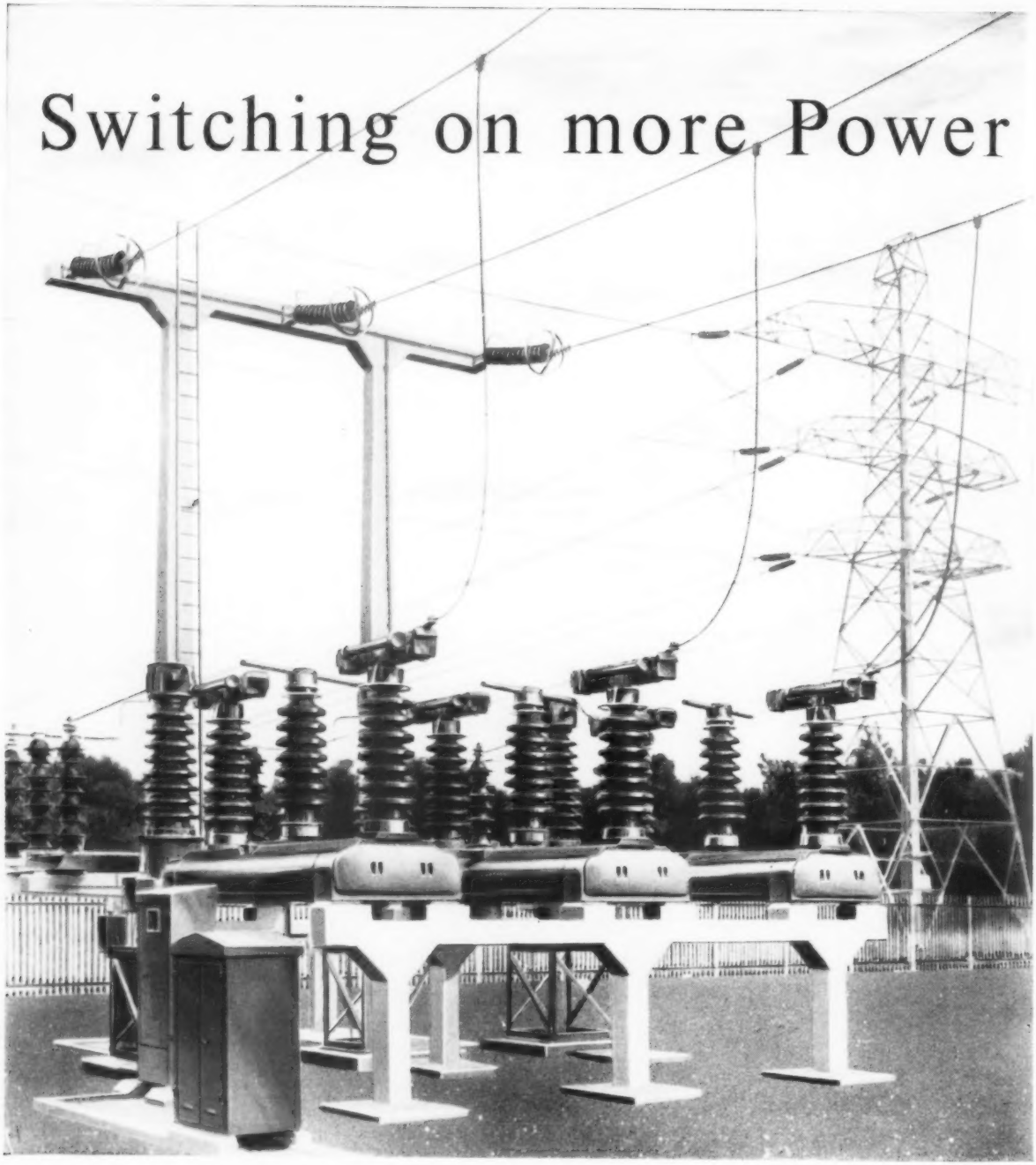
—articles on construction and design changes pp 74-88

Also in this issue:

Conference reports from Vienna and Stockholm

ember 1960 monthly 3/6

Switching on more Power



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VOL 5 NO 55 NOVEMBER 1960

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SPECIAL FEATURES

BUILDING THE UK's NUCLEAR POWER STATIONS

Experts from the consortia outline main design changes and describe construction methods, which differ markedly from conventional power station techniques

Berkeley *by Mr J. R. M. Southwood, Mr E. L. Haste, et al* 74

Bradwell *by Mr R. D. Vaughan, Mr A. Young and Mr E. Anderson* 77

Hunterston *by Mr D. W. T. Angwin and Mr A. N. H. Bond* 80

Hinkley Point *by Mr W. Wadkin and Mr D. F. Hutton* 83

Trawsfynydd *by Mr J. N. Bishop* 86

The Soviet 50 MW intermediate reactor
Use of epithermal neutrons has resulted in interesting design features 89

Industry speaks on exports
Frank, expert and sometimes astringent comment by chief executives on export prospects and official policy in reply to our confidential survey 90

Buying a nuclear power station
A strikingly different approach to the customer's purchase problems is made by Mr Robin Guard 92

Harwell's spent fuel irradiation ponds
Spent Dido and Pluto elements are put to work 95

Interkama II—Instrumentation and Control Exhibition 96

High Voltage's International Particle Accelerator Conference 96

Small and Medium Power Reactor Conference
The IAEA's first major conference was attended by some 260 delegates. Mr A. E. Powell and Mr T. C. Leader highlight some of the 63 papers read 97

Internal cathodic protection
A well designed protection scheme insures against corrosion failures and saves money. It is to be used at Windscale and Winfrith Heath 101

International Instruments and Measurements Conference
The fifth Stockholm conference showed increasing emphasis on reactor control. Dr D. Taylor reports both on the papers read and the exhibition 104

Fuel element test tower
Bradwell reactor components are being tested in Parson's 120 ft facility 109

REGULAR FEATURES

Progress in industry
CO_2 circulators for AGR, Mobil's gamma test rig, Battelle's plutonium laboratory, etc 111

Letters 65
Editorial 67
Worldview 69
Students' Notebook 110
Points from Papers 114
Cross-Section *Gracchus* 115
New Product survey 116
Business News 120
Diary 122
Industrial Literature 122
People 124
Book Reviews 126

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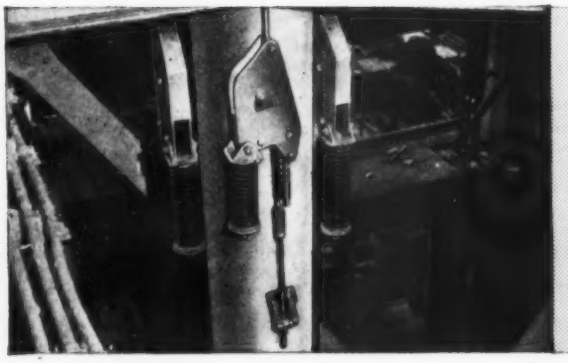

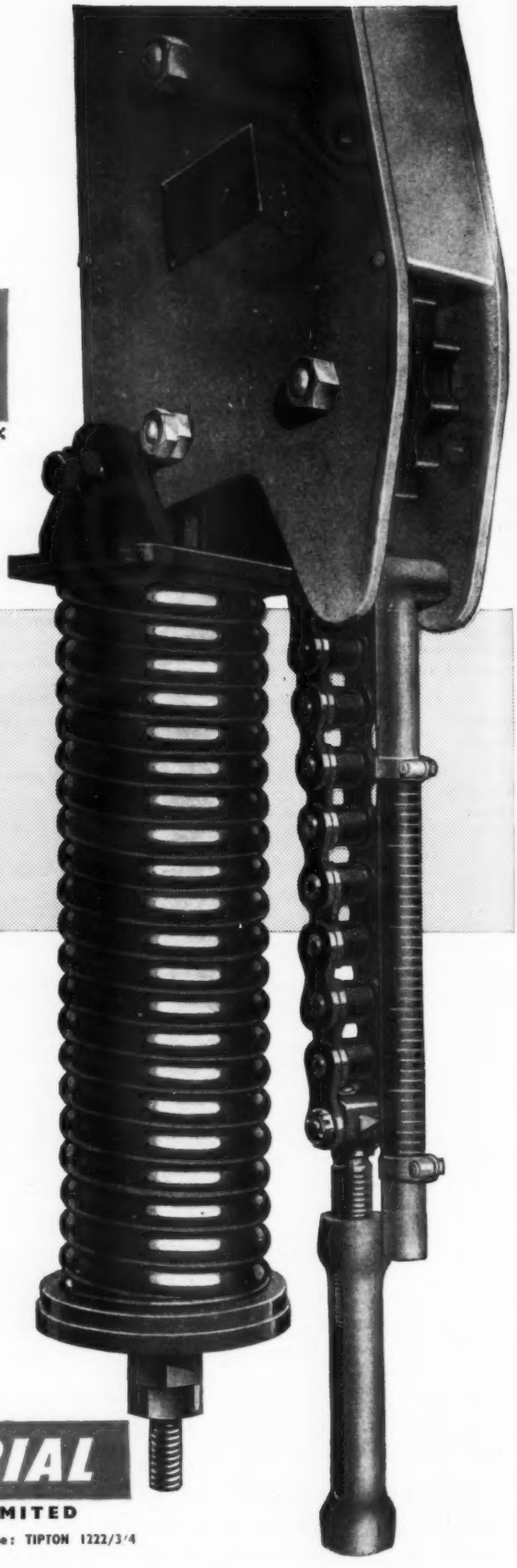

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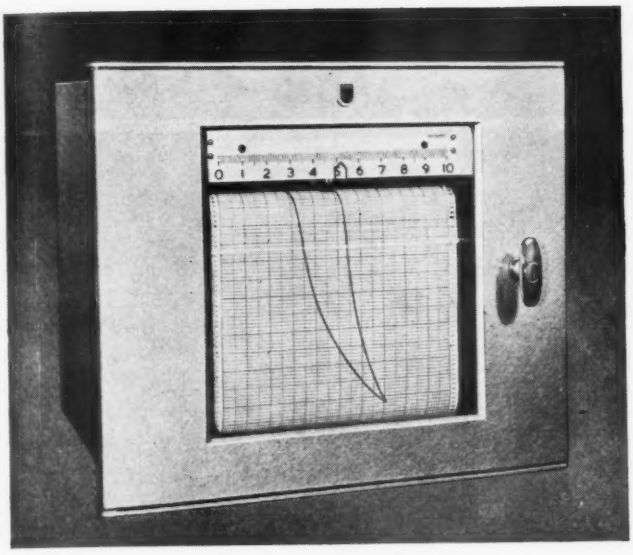

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0..... 10 mV	0..... 10 mV
0..... 20 mV	0..... 20 mV
0..... 50 mV	0..... 50 mV
0.....100 mV	0.....100 mV
0.....200 mV	0.....200 mV
0.....500 mV	0.....500 mV

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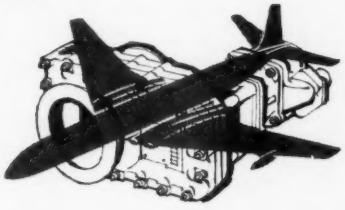

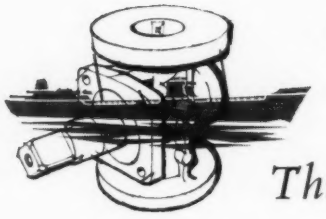

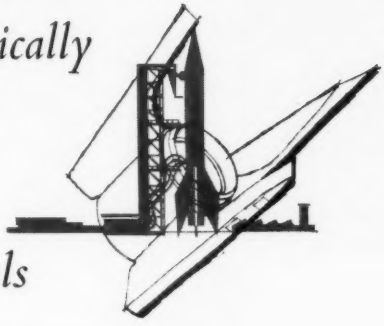

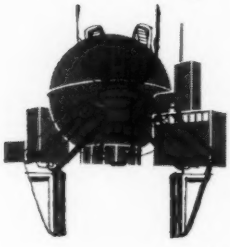

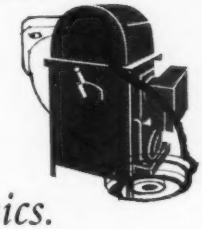

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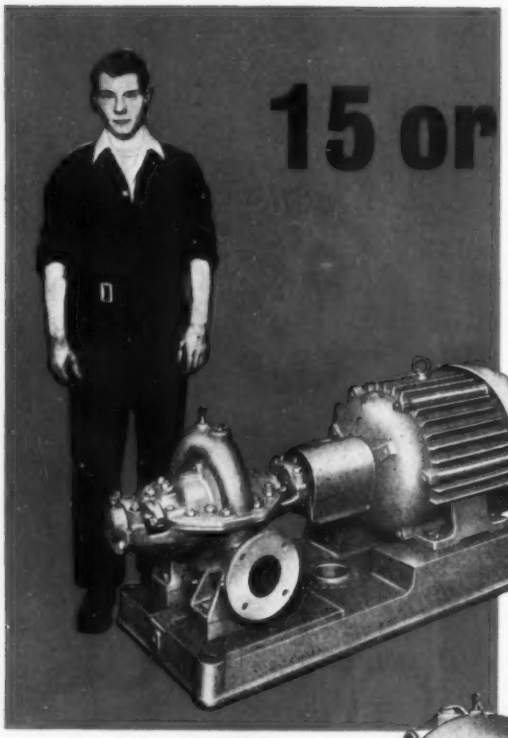

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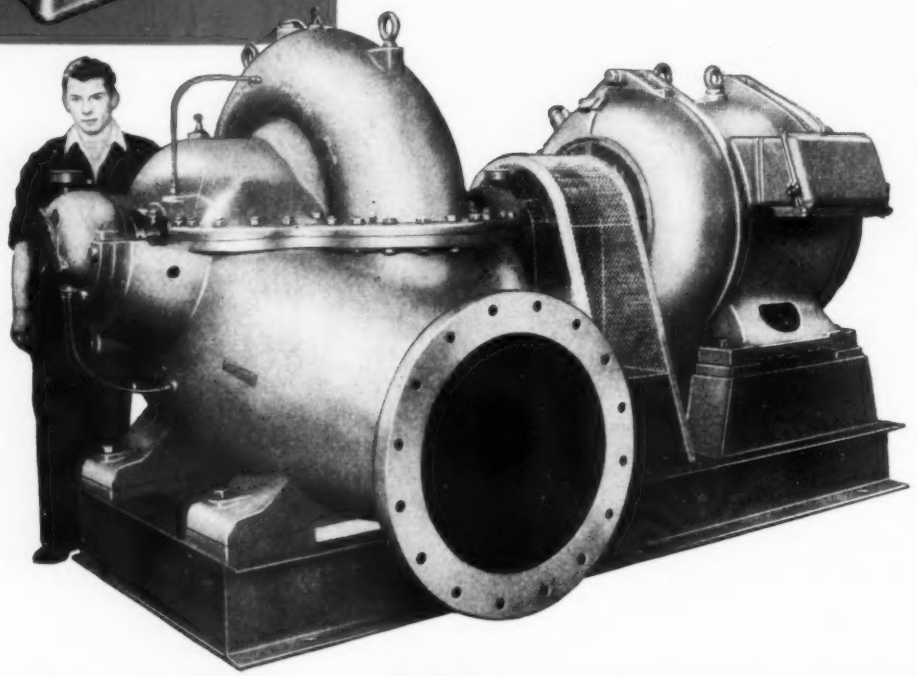

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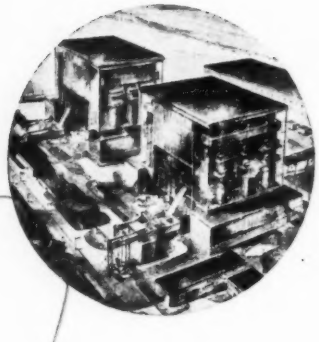

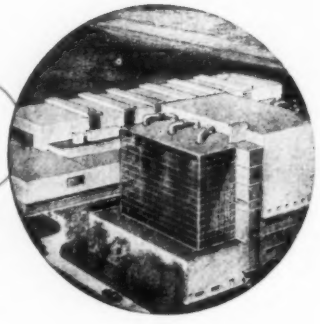

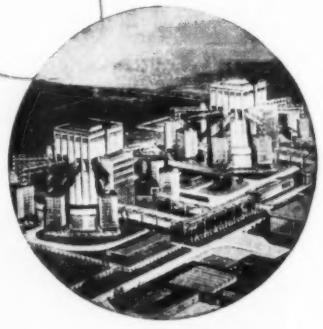

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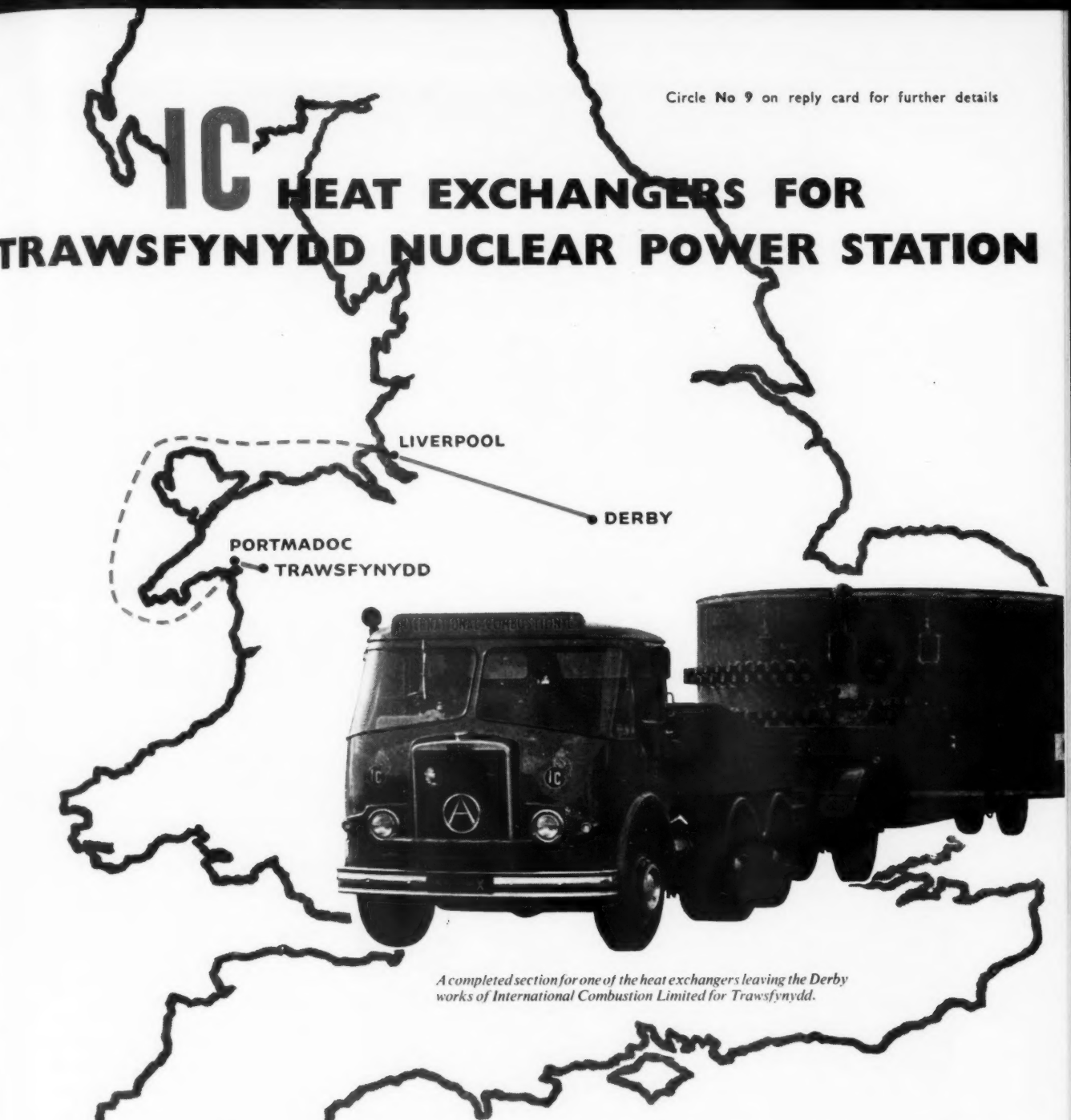

A completed section for one of the heat exchangers leaving the Derby works of International Combustion Limited for Trawsfynydd.

The development of Portmadoc harbour and associated road improvements to site reflects the detailed planning behind the construction of the Central Electricity Generating Board's Trawsfynydd Nuclear Power Station. The full use of the most suitable and economical transport again shows the active co-operation between Atomic Power Constructions Limited, their member companies, their contractors and the C.E.G.B.

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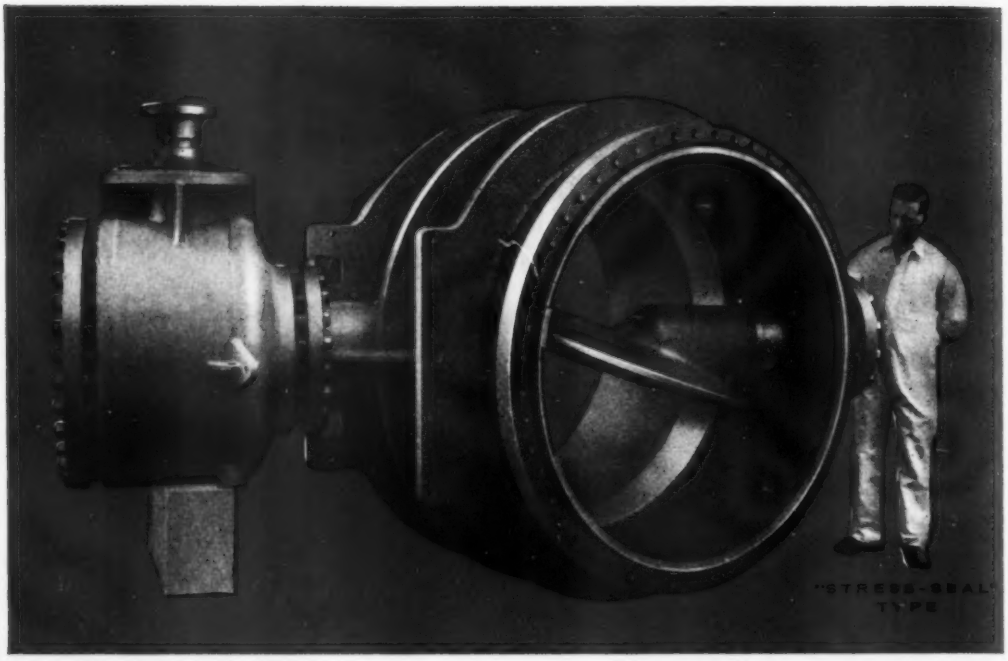
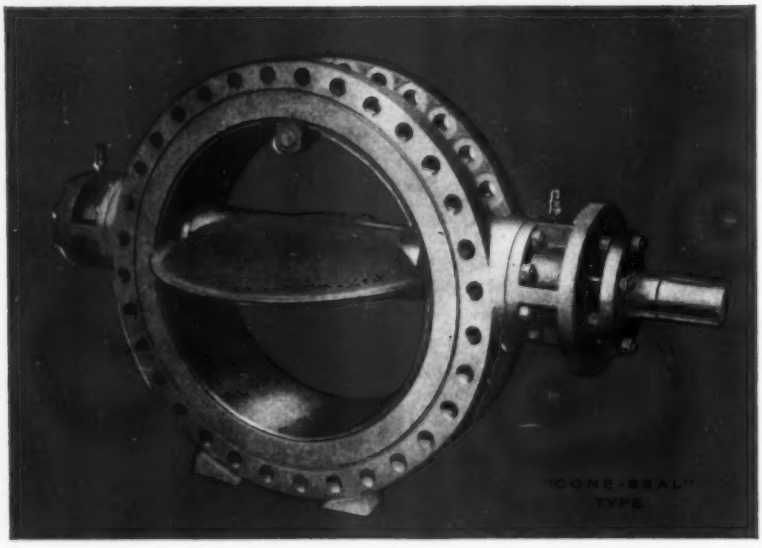


REACTOR GAS VALVES



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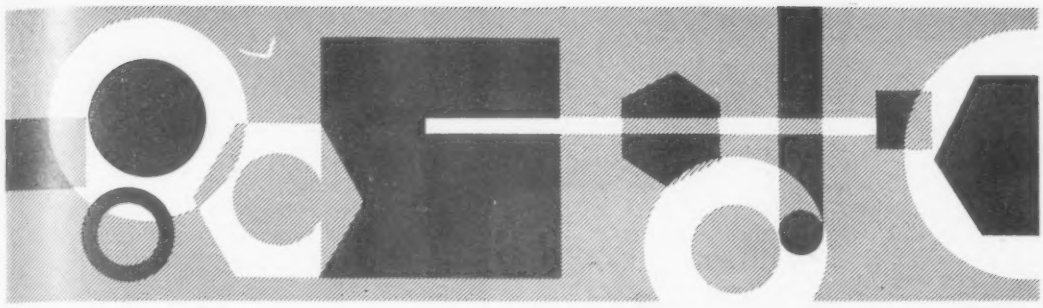

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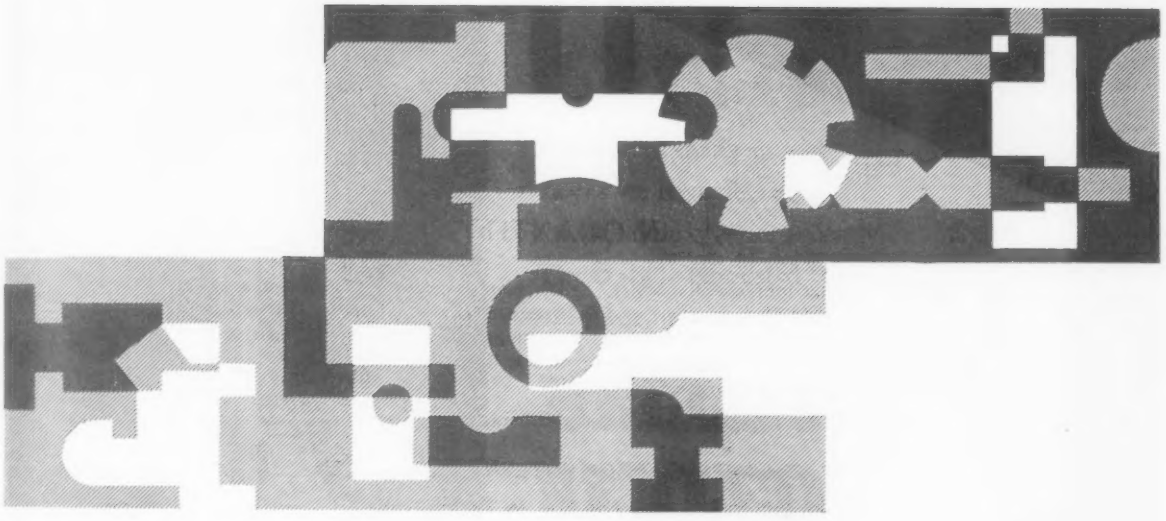

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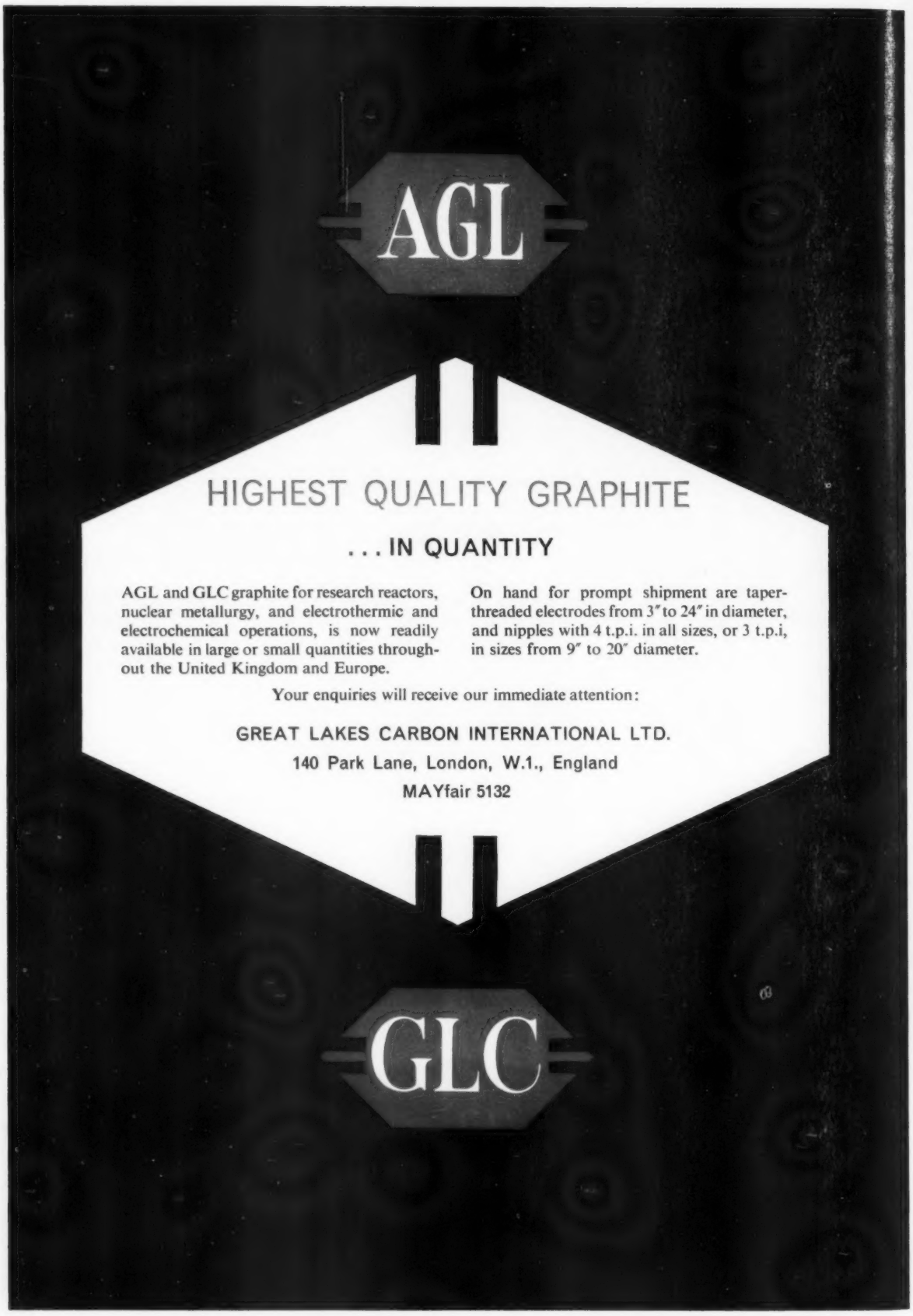
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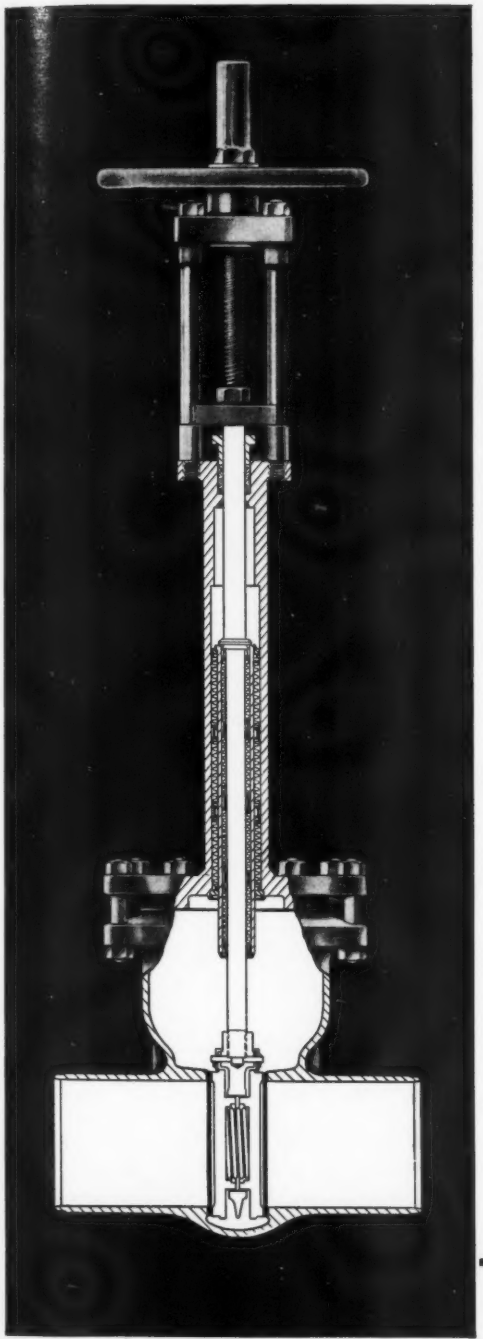

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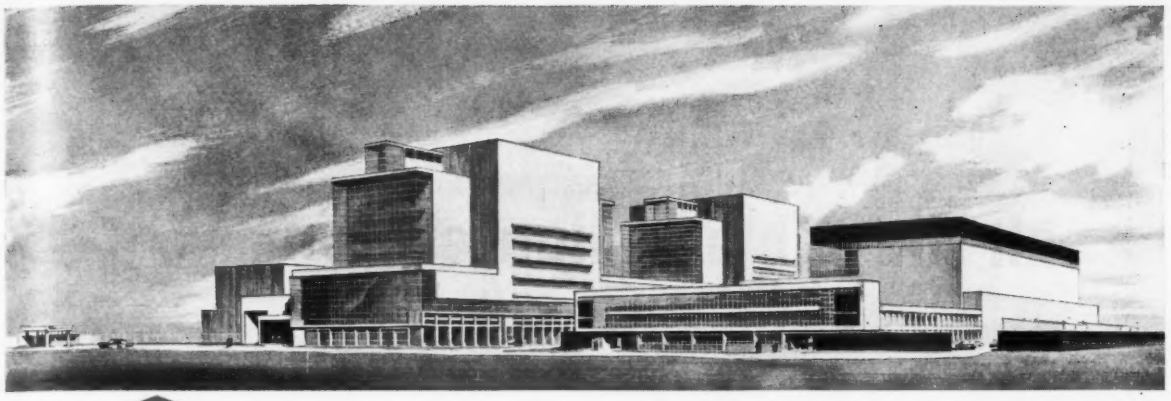

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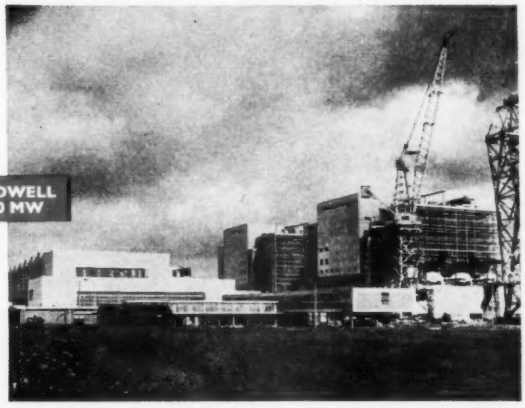
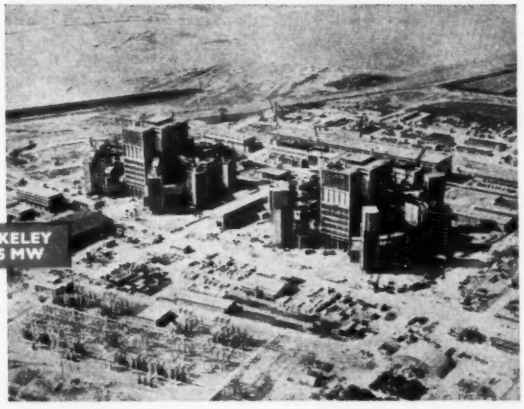
DUNGENESS

—550 MW

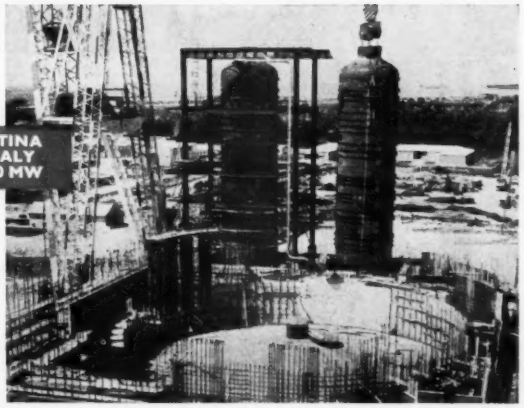
On the shingled headland of Dungeness, Kent, Britain's newest and largest nuclear power station is being built by The Nuclear Power Group for the Central Electricity Generating Board. The station will incorporate the latest developments in reactor technology and will be the most efficient of its kind. Dungeness is the outcome of experience and know-how, for The Nuclear Power Group are also constructing Britain's first two nuclear power stations at Berkeley and Bradwell and the Italian station at Latina near Rome.



BRADWELL —300 MW



BERKELEY —275 MW



LATINA ITALY —200 MW

TNPG ... *leaders in nuclear power*

The Nuclear Power Group

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TNPG/2

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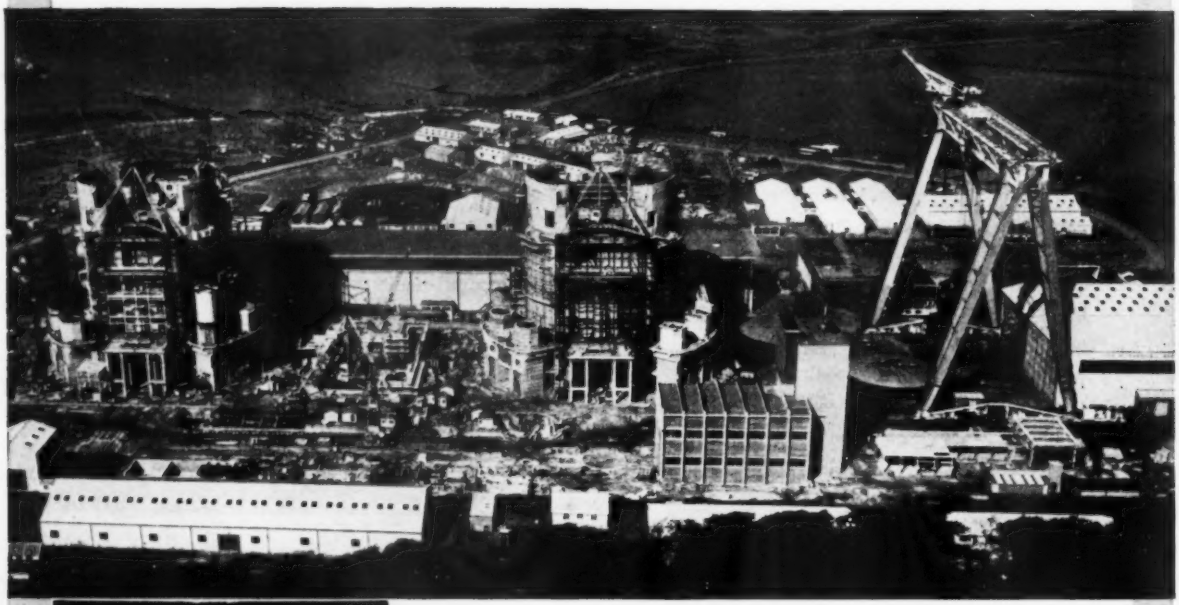
all the cable at Hunterston

is pg

19,500 yards of Pirelli-General 132 kV. single-core oil-filled cable are being installed between the transformers at the power station and switching station. The insulation of this cable is designed for 110 kV/cm. maximum working stress.

With the completion of this installation the whole of the cabling at Hunterston will have been carried out by Pirelli-General.

Hunterston is being constructed by the G.E.C.-Simon-Carves Atomic Energy Group. Consulting Engineers to South of Scotland Electricity Board, Kennedy and Donkin.



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PIRELLI-GENERAL CABLE WORKS LIMITED

SOUTHAMPTON AND EASTLEIGH

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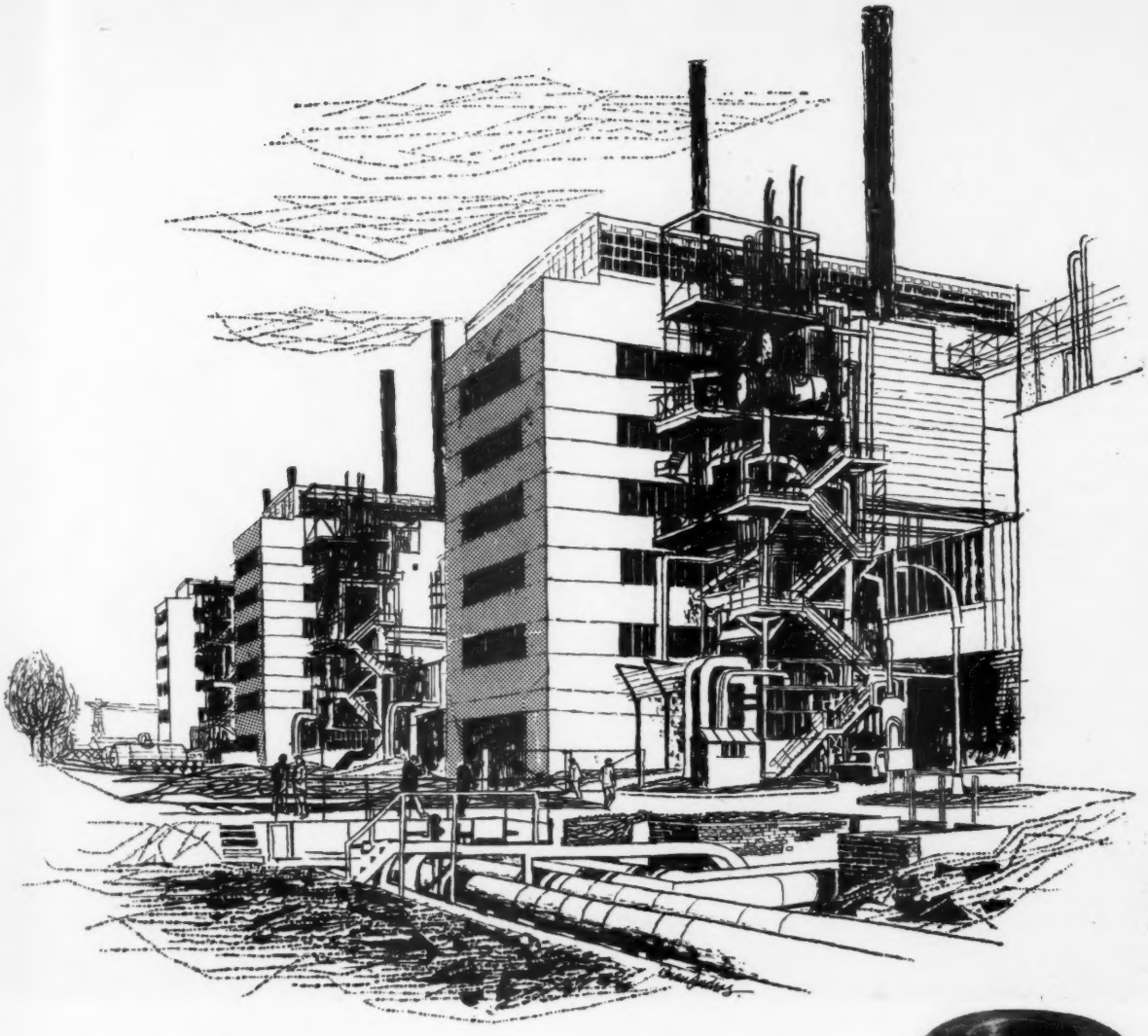

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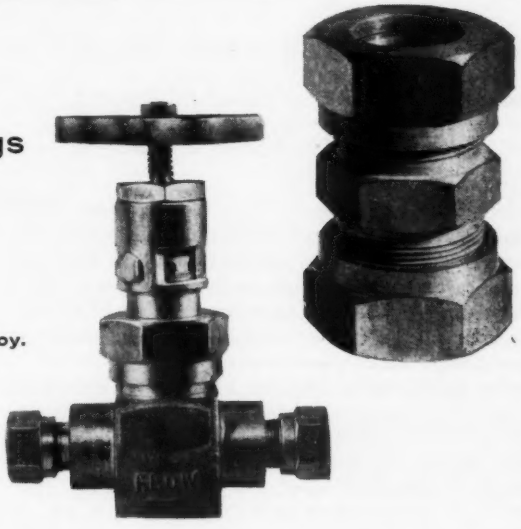

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"Biz AMF i seçtik" "私達はAMFを選んだ" "Wij geven de voorkeur aan AMF" "אנחנו בחרנו ב-A.M.F."

"Nos escolhemos AMF" "ہم نے اے ایم ایف پسند کیا ہے" "Wir haben AMF gewählt" "Εξελέξαμεν την A.M.F."

"Hemos escogido AMF" "لقد اخترنا شركة أ.م.ف" "Abbiamo scelto AMF" **"We chose AMF"**

This decision has been made 21 times and in 12 languages by representatives of universities, atomic energy commissions and research institutes charged with the selection of the best research or training reactor for their needs. While the claim of leadership based on quantity of output is often a hollow boast, *in reactor technology and construction it has extraordinary significance.*

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AMF's record starts with the Battelle Memorial Institute's pool-type reactor, in operation since 1956, the pioneering effort in research reactor standardization. The roster of AMF design and fabrication innovations, all of them developed to meet special customer needs, is unmatched.

AMF utilizes its vast mechanical experience in the production of a wide range of reactor components and auxiliary equipment, including: Reactor servicing equipment • Control rod drive assemblies • Standard and heavy-duty manipulators.

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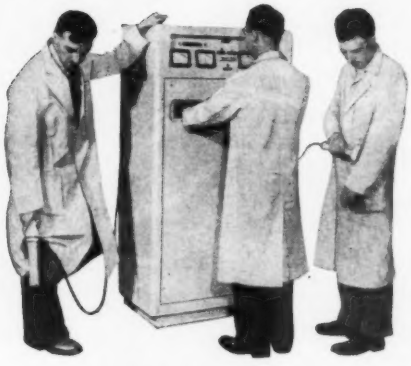
NUCLEAR SAFEGUARDS



Hand and Clothing Monitor

Portable Monitor

E.M.I. INSTRUMENTS PROTECT AGAINST RADIATION HAZARDS

The Hand and Clothing Monitor has been specially designed to cope with large numbers of staff. Whilst Alpha and Beta contamination are being simultaneously checked on both hands, the footwear and clothing of two other workers are being screened.

The speed, simplicity and safety of E.M.I.'s new Monitor have been recognised by large orders from the U.K.A.E.A. and authorities in many other countries.

- ✳ Complete Alpha and Beta hand count in 5 seconds.
- ✳ Audible and visible warning of the maximum permissible contamination level.
- ✳ Audible warning if hands are removed too soon.
- ✳ Dual phosphor scintillation counters for increased efficiency in tropical and humid environments.
- ✳ Automatic correction for background radiation.

The Portable Monitor is the answer where mobility is required. Compactness *and* high accuracy have been achieved by combining all-transistor circuitry with the E.M.I. dual phosphor technique. This instrument, developed in close collaboration with U.K.A.E.A., marks a really significant step-forward in radiation detection.

- ✳ Simultaneous monitoring of Alpha-Beta radiation, giving aural and visual warnings.
- ✳ Transistors throughout for reliability, lower power consumption and long life.
- ✳ Battery operation for real portability (mains unit available if required).
- ✳ High accuracy over wide temperature range.

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P4894

EKCO Thermocouple Trip Amplifier

SPECIFICATION

Operational Trip Setting. 0-600°C.

Trip Margin Meter Indication. 50°C. below trip.

'Low-Margin' Trip. May be set anywhere within the available trip margin range.

Trip-Accuracy. 0.4% of trip temperature.

'Low-Margin' Trip Accuracy. Better than 2% of the meter range. (Accuracy limited because the meter is used for setting).

Hysteresis and Stability of Both Trips. 2% of meter range.

External Facilities. The warning and trip relays each provide the following facilities which are connected to plugs at the rear of the instrument:—two sets of change-over contacts and two short circuit pairs.

Input Signal Required. 40 μV/°C.

Thermocouple Earthing. Can be at either terminal or at the hot point. (The amplifier is isolated from earth).

Stability. Cold junction compensation ensures that performance remains within the limits specified up to 40°C. ambient temperature. Performance is unaffected by mains variations of +8% —20%.

Thermocouple Resistance. Up to 250 ohms for performance specified. Up to 500 ohms for ambient temperature ('cold junction') up to 30°C.

Response Time. Less than 0.2 seconds.

Recorder Output. A 100 mV recorder can be driven to indicate the meter reading at an impedance of 100 ohms.

Dimensions. Front panel 4″ wide x 8¾″ high. Depth 13″.

Mains Input. 110-120v or 200-250v A.C., 45/60 c/s.

Mains Consumption. 20 watts approximately.

N642A

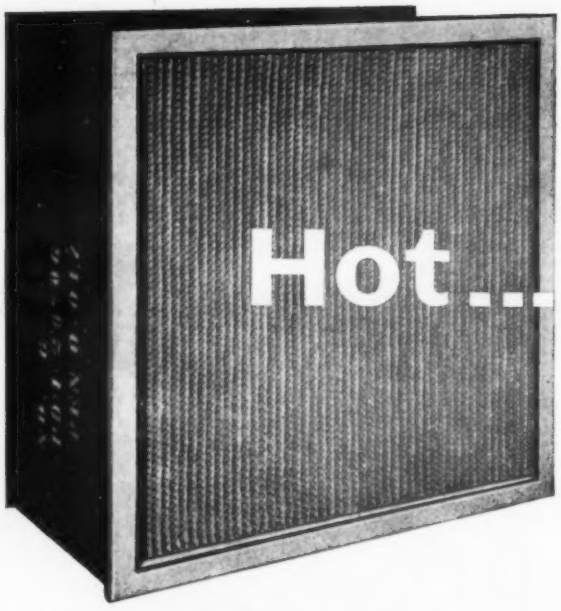
The Ekco range of reactor instruments also includes the following:—

Reactor Period Meters with alternative ranges.
Reactor Power Error Meter.
Resistance Thermometer Trip Unit.
Shut-Down Amplifier (with start-up facilities and shut-down state trip).
Fast Neutron Monitor (installed).
Misalignment Indicator (for coarse control arms.)
Leak Indicator (for external heavy water leak).
Effluent Monitor.
Battery Box Assemblies.
Logarithmic Gamma Health Monitor (installed).
Slow Neutron Survey Meter (portable).
Beta-gamma Survey Meters (portable).
Decade Voltage and Current Generator (general purpose test unit).
Reactor Period Meter Test Unit.

EKCO ELECTRONICS LIMITED

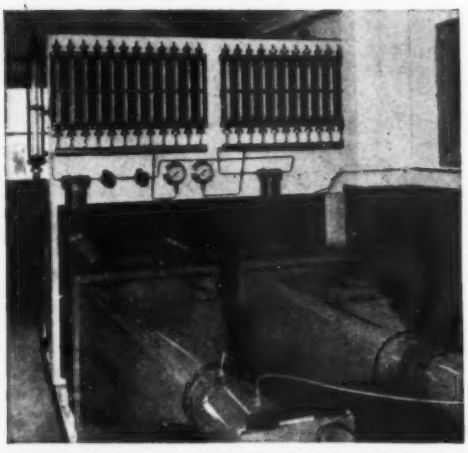
Sales Dept., Southend-on-Sea, Essex. *Telephone:* Southend 49491

Installation & Service Dept., Ekco Electronics Works, Rochford, Essex. (Rochford 56866)



but not bothered

Vokes high temperature 'Absolute' filters



Vokes High Temperature 'Absolute' filters are tested in accordance with BSS. 2831 on the methylene blue test rig illustrated above. Every filter is subjected to a stream of air containing particles of methylene blue 'dust' ranging in size from 0·1 to 0·5 microns, and rejected if its efficiency is less than 99·99%. Vokes is the only British company which *guarantees* minimum performance figures in this way and Vokes filters are therefore widely used in all applications which require *scientific* filtration.

These filters have been designed for applications involving very high temperatures or risk of fire — for example in nuclear power stations where a breakdown in the filtration system due to an outbreak of fire might release dangerous toxic particles into the atmosphere.

They will withstand temperatures up to 1,000°F and are available in standard sizes as manufactured for the Atomic Energy Authorities. Similar in appearance to the 55 'Absolute' panels from which they were developed, Vokes high temperature filters have an all-glass paper filter medium with aluminium separators, refractory sealers and metal frames. The efficiency of this type of 'Absolute' is even greater than the very successful '55' panel, giving a penetration of only 0·01% against a methylene blue dust cloud.

A booklet on Vokes special purpose air filters is available on request.

The APPROVED filter for fire resistant applications

(Pat. applied for)

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V.534

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There are perhaps a hundred paths the pylons could follow. *One* must be chosen. Not plotted arbitrarily across a map, but thoughtfully, carefully sited, so that pylons and cable strike the best possible balance with the landscape.

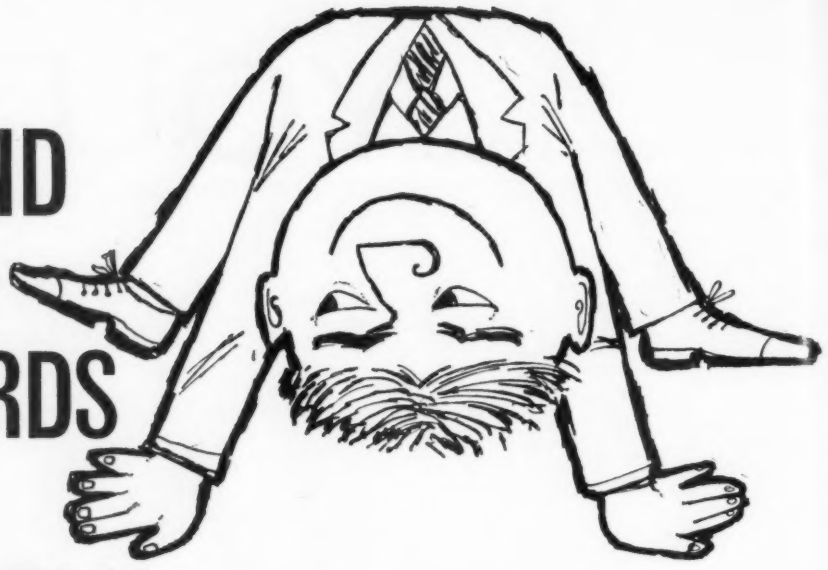
The Central Electricity Generating Board are just as concerned about this as they are about bringing in the power. For the nation has charged the Board with a double duty. Not only to maintain an efficient, economical electricity supply, but also to preserve the amenities of the country as they go.

That's why the new line will be planned so that it follows the dark background of a wood here; skirts a village there; crosses skylines in the most inconspicuous way to be found; and eventually reaches the town through its industrial suburbs.

These advertisements are appearing in the farming and country magazines. The Central Electricity Generating Board thank electrical contractors for their co-operation in the past, and know that they will do all they can to preserve the amenities of the countryside.

THE CENTRAL ELECTRICITY GENERATING BOARD CEGB

WE BEND OVER BACKWARDS QUITE REGULARLY



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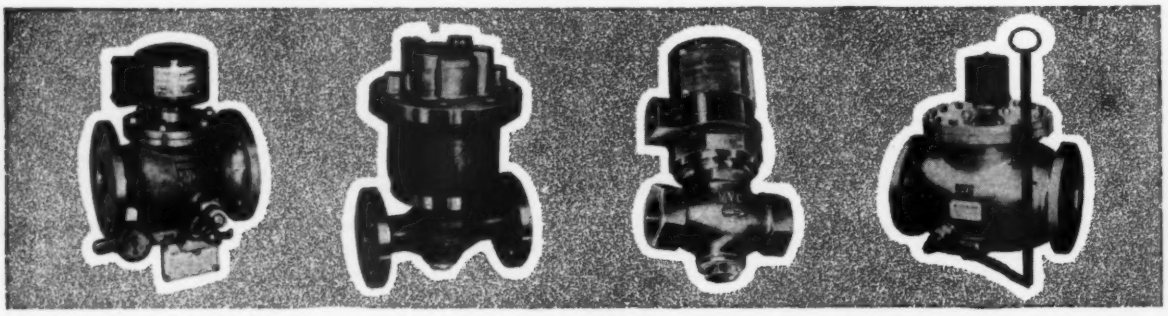
and to see that our customers are happy!
Over 30 years' experience and 'know-how' has been built-in to our range of over 100 automatic control valves. People control water with them, gas with them, oil with them, steam with them and a host of other industrial liquids and gases too! Mushrooms are grown with them, jam is made with them and ships cargoes are frozen with them!
You'll find that expert consultation and advice cost you absolutely nothing at MVC. Our full experience is at your disposal. Many times, what has first appeared to be impossible has been achieved! Why not write *now* for our new comprehensive catalogue No. 45 which contains full details of our complete range!



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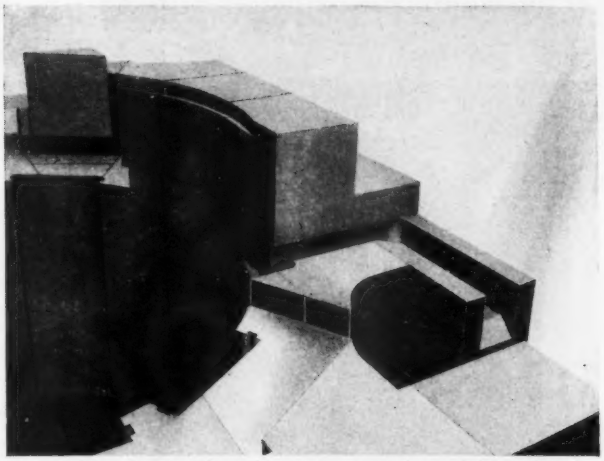

Sections of a "Jason" reactor recently completed for the Hawker-Siddeley Nuclear Power Co. Ltd.

GRAPHITE MACHINING

Powell Duffryn Carbon Products Limited — the leading machinists of Nuclear Graphite.

Official Graphite machinists for the General Electric Co. Ltd. Current contracts cover important work at: Hunterston, Berkeley, Bradwell; also for Hawker-Siddeley Nuclear Power Co. and U.K. Atomic Energy Authority.

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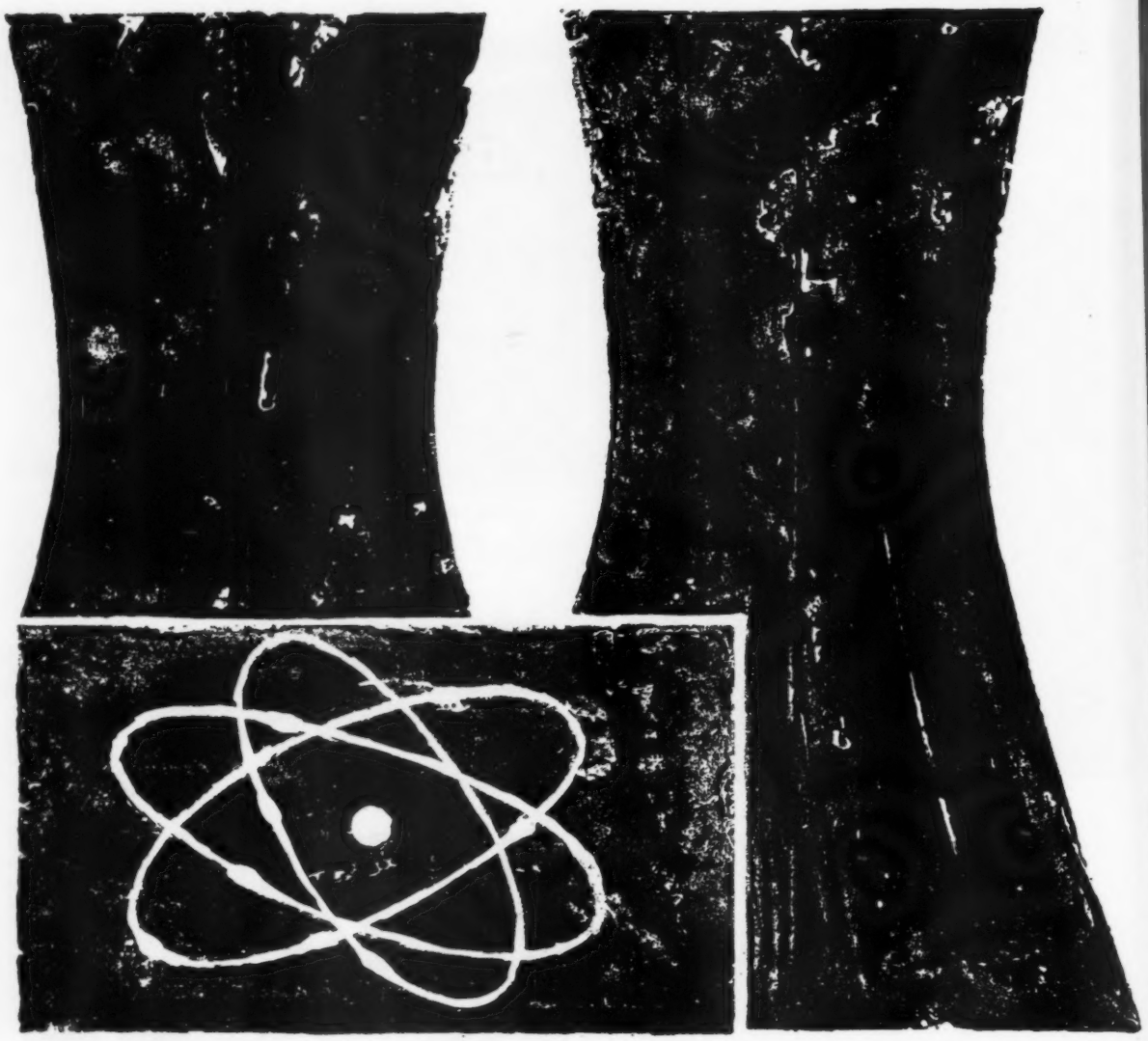

ARGUMENT FOR ALUMINIUM Aluminium is indispensable in nuclear engineering - for cladding reactors, for fabricated pipework and heat exchanger tubes, for such diverse ancillary equipment as glove-boxes, remote control gear and treadplate. **IMPALCO**, backed by ICI and ALCOA, has both the production facilities and the technical know-how to meet the needs of this exacting industry. Wherever there is an argument for aluminium's lightness, durability, good conductivity, ease of handling - contact **IMPALCO** through your nearest ICI Sales Office.

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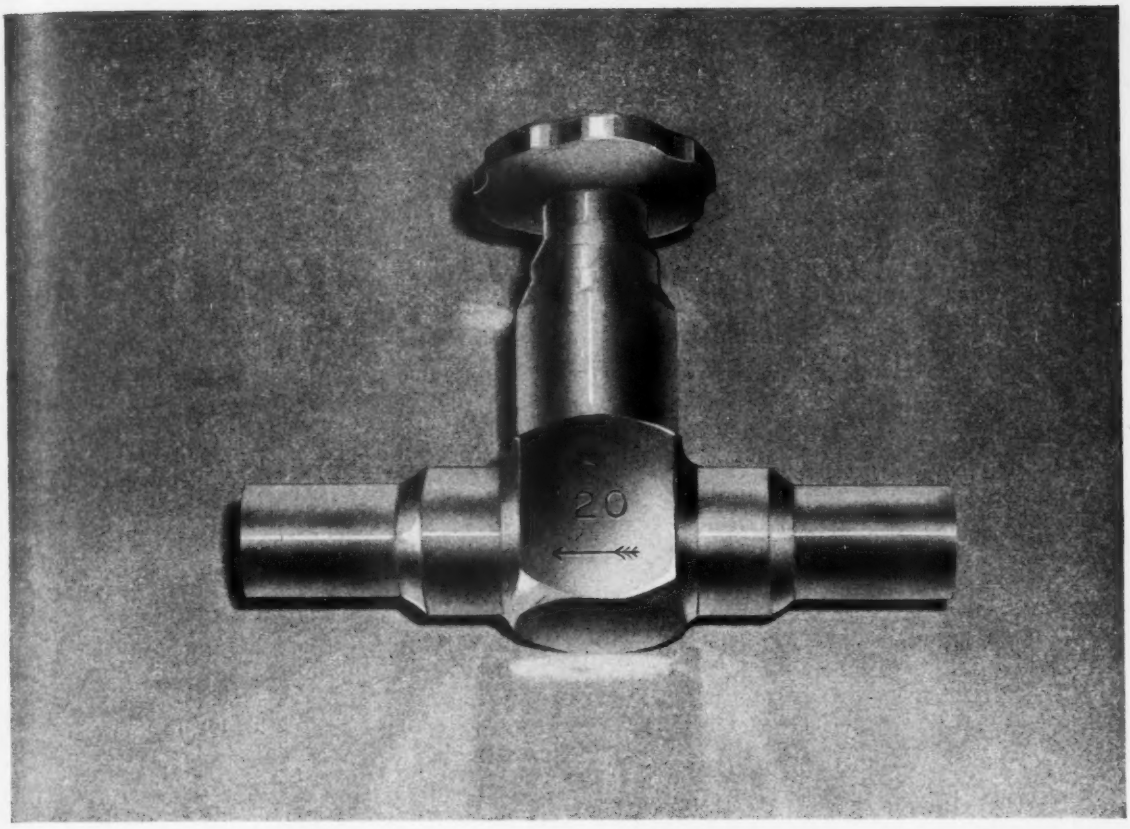
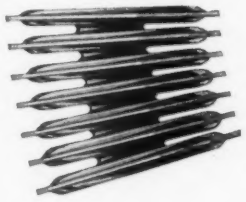


Gachot Stainless Steel Bellows Sealed Valve



Approved by British and Foreign Atomic Energy Commissions for use with radioactive media.

350 lbs per sq. inch

suitable for pressures up to 350 lbs per sq. inch and temperature of 400 C.

400° Centigrade

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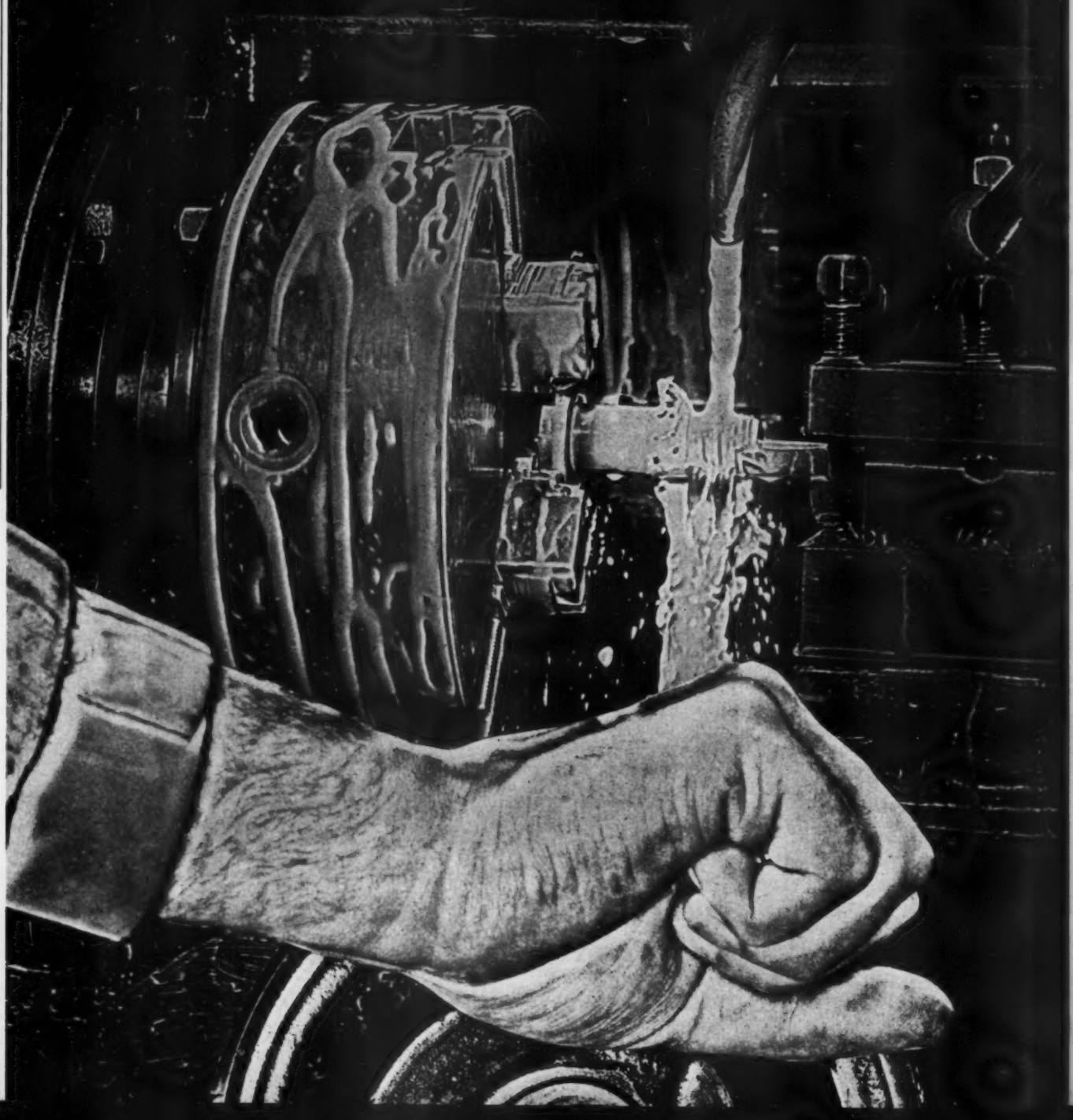
Greater safety for hands



With new Shell Dromus Oils

Most modern soluble cutting oils contain phenolic compounds used as coupling agents between the oil and the emulsifier, for better blending and easier mixing. These phenolic compounds can cause skin irritation, especially where modern high-speed machines are used and the emulsion can concentrate, through the evaporation of water, above the safety level.

Shell research chemists have been working on this problem, which has been causing some concern to Management. After considerable research, Shell Dromus Oils have been reformulated and these new cutting oils now produce bland emulsions, which considerably reduce the risk of skin trouble to operators.

The real difficulty was to find a new coupling agent to replace the phenolic compounds, and Shell finally used what their chemists know as a higher fatty alcohol complex. This solved one problem, but presented another. The new coupling agent was volatile at the high temperatures normally used in blending processes. Further research found a solution to this problem by designing and installing new plant.

The new Dromus Oils are every bit as efficient as before and cost no more. They put Management in the welcome position of being able to minimise working hazards at no extra cost. And machine men need no longer be so worried about skin troubles.

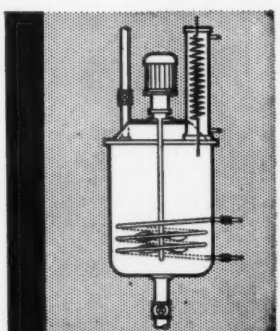
The moral of the story is that Shell research is supremely applicational. The centre at Thornton is always ready to work with even the most specialised sectors of industry to produce the right oil for the job. If you and your organization have any major lubricating problems, it pays to get in touch with your local supplier of Shell Industrial Lubricants.

The Research Story

Shell chemists in the U.K., in Holland and in the U.S.A., prepared and examined hundreds of experimental soluble oils, and established that certain combinations of fatty alcohols could be used in place of phenolic compounds with no loss of efficiency. They set to work to discover the best combination and developed a higher fatty alcohol complex which fitted exactly. Then they realised that to blend this new coupling agent into soluble oils would require special plant and new blending techniques.

Exhaustive testing of blend stability, emulsion stability, anti-corrosion and machining properties led to selection of the most promising blends. A pilot plant was set up to produce batches of these for use in field trials.

This field testing and final development proceeded for two years whilst production plants were erected at points so chosen as to give the most economical and rapid delivery throughout the United Kingdom.



This is the blending kettle. The reflux condenser beside the stirrer motor prevents the loss of constituents volatile at the blending temperature.

NEW SHELL DROMUS SOLUBLE CUTTING OILS

another proof of Shell leadership in lubrication

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ATOMIC FAIREY

What are Fairey's doing in Atomics? What aren't they? Aluminium and steel fabrications, charge machines, control mechanisms, graphite machining and laying, irradiated fuel disposal equipment, gas filtration . . .
At Britain's latest nuclear power station at Trawsfynydd, as in so many other projects, Fairey are there . . . at the heart of things. They are at work on a major programme of research, development, design and manufacture for nuclear power stations and experimental establishments throughout the country. Fairey have been thinking and living nuclear engineering for years—they know what they're about.
Fairey's nuclear work includes: U.K.A.E.A. experimental reactor equipment, power reactor equipment, fuel element cans, controlled thermonuclear research equipment, aluminium and steel fabrications nuclear fuel processing equipment, plastics and plastics fabrications, electronics and special instrumentation, machine tools and remote handling equipment, hydraulic equipment and gas filters.

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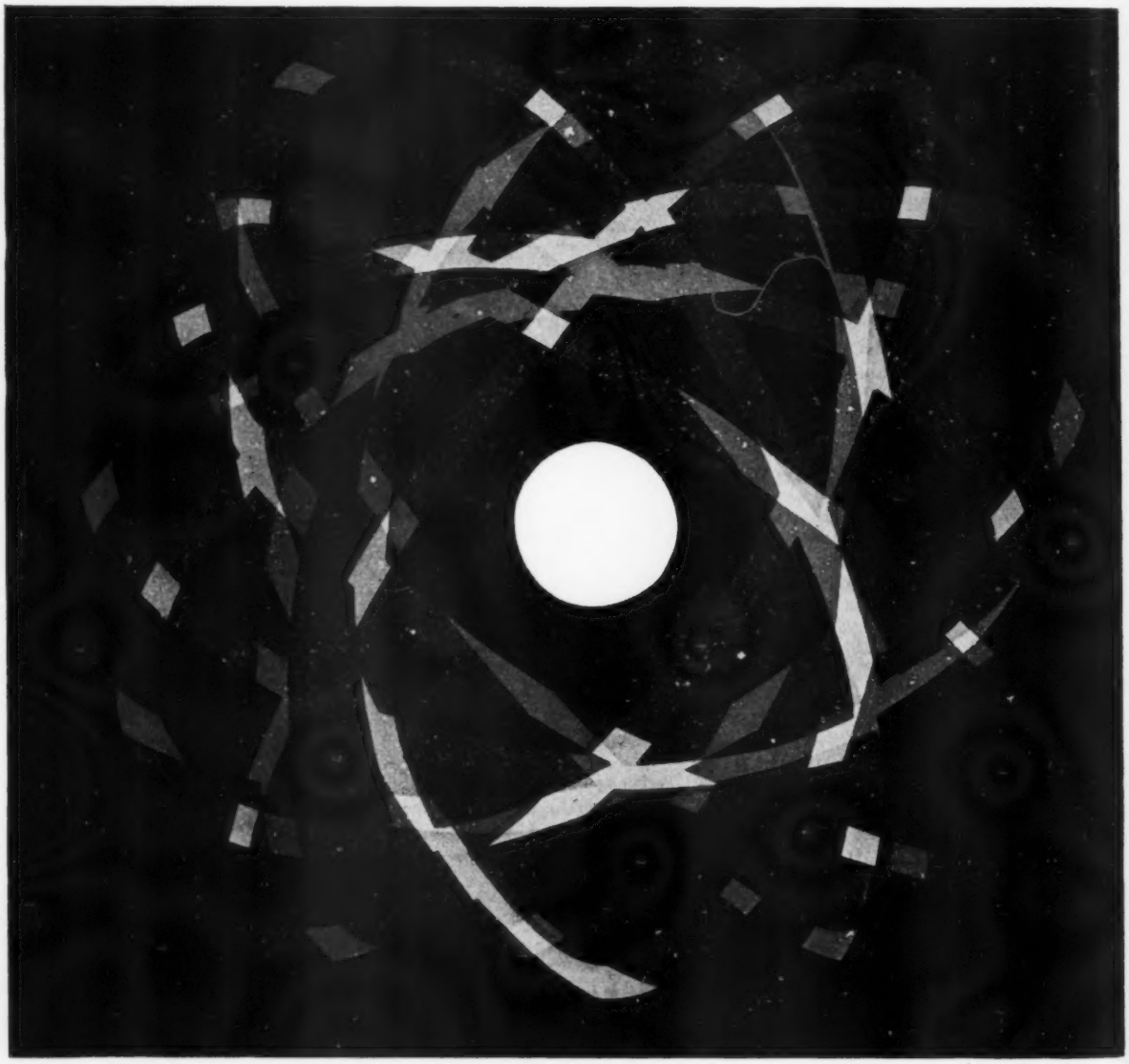

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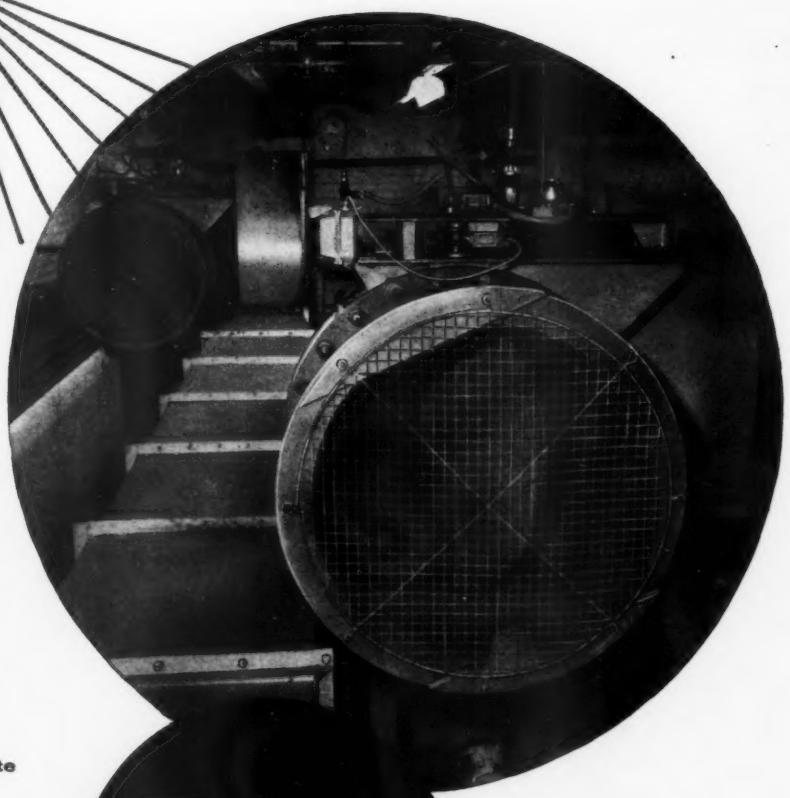

These Boving 30 inch hydraulically operated Butterfly valves are installed at a St. Helen's glass works, where they control the flow of air in a toughening plant. Opening and closing once every 40 seconds, they operate no less than 11,000 times in a normal working week. The medium controlled-air—affords no lubrication, and yet the valves operate month after month continuously trouble-free, always providing a complete seal. This is yet another example of the durability and long-term reliability provided by Boving Butterfly Valves fitted with the Boving inflatable rubber seal.

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BUTTERFLY VALVES

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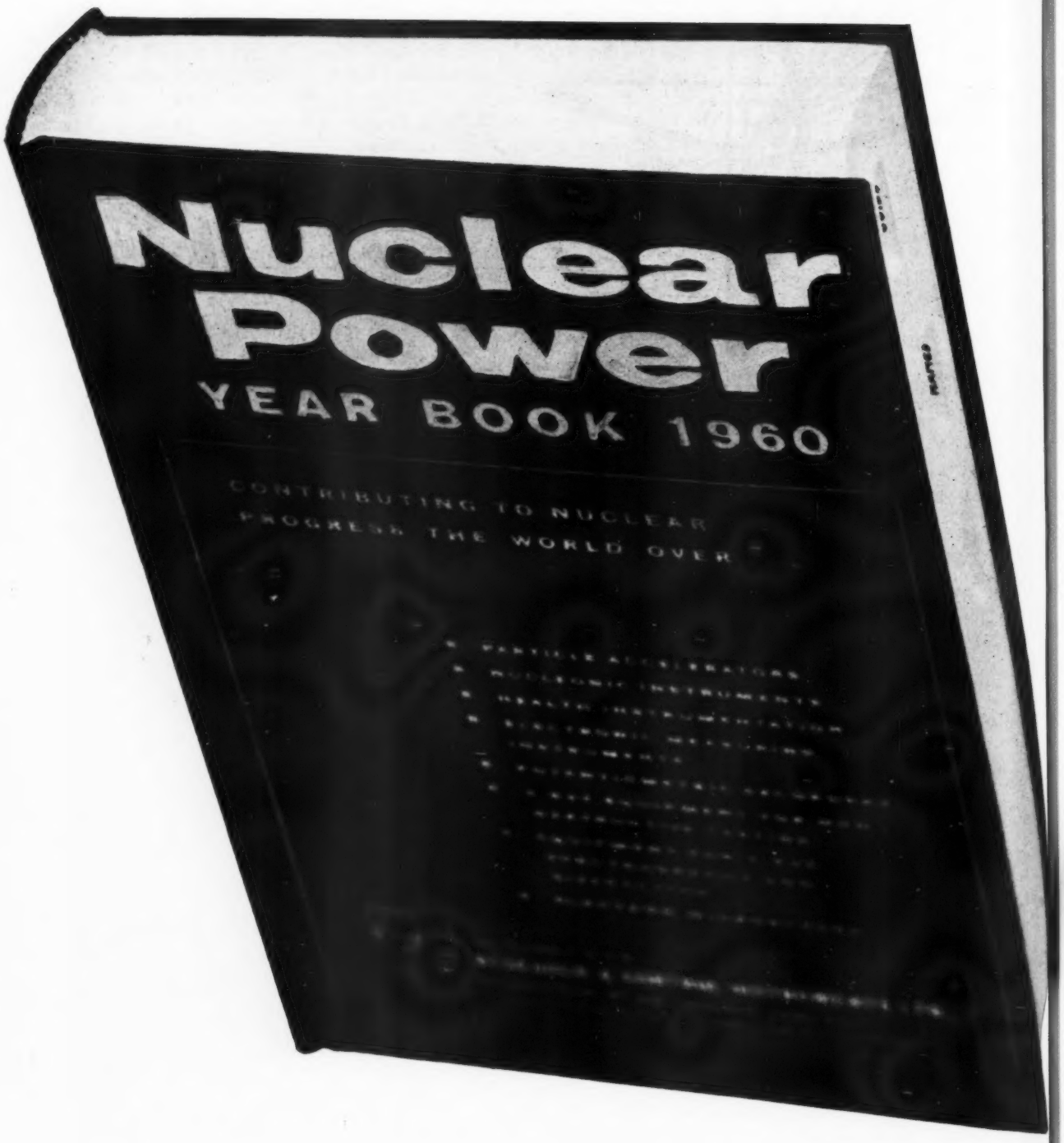
P.4990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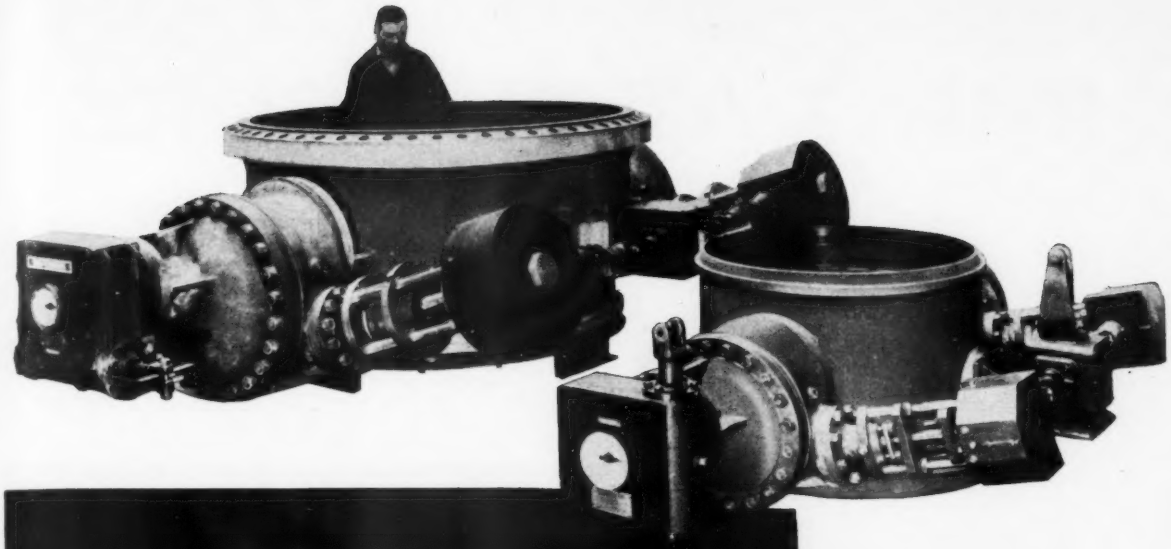
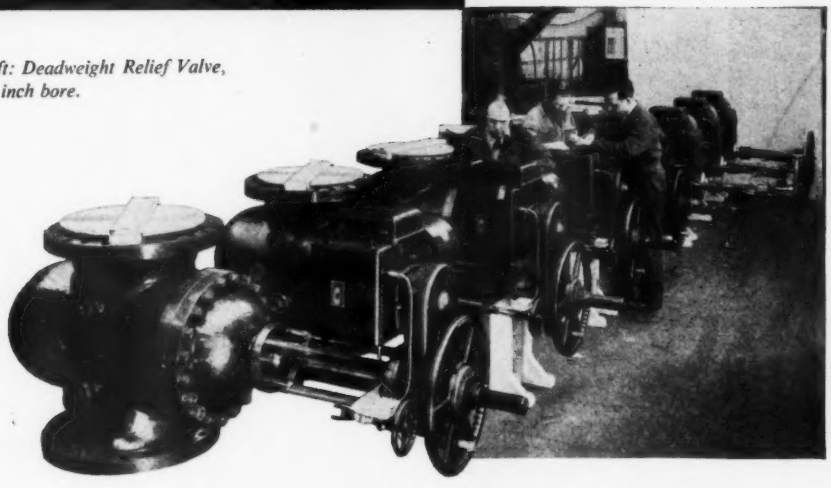


HOPKINSONS' VALVES FOR NUCLEAR POWER STATIONS

Above: "Tansphere" Valves for isolating CO_2 gas between reactor and steam generating plant. Supplied or on order for Bradwell, Hinkley Point, Latina and Trawsfynydd (Valves illustrated are 60 inch and 36 inch bore).

Below: Group of 24 inch electrically-controlled Hopkinson-Ferranti valves for a nuclear power station.

Left: Deadweight Relief Valve, 20 inch bore.



Specialised valves (some of which are illustrated) needed in nuclear power stations are naturally entrusted to Hopkinsons because of their vast experience in the manufacture of valves for exacting duties. But, additionally, Hopkinsons are supplying large numbers of their electrically controlled valves, desuperheating equipment, combined stop and isolating valves, automatic exhaust valves, steam traps and all types and sizes of stop valves.

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HV121

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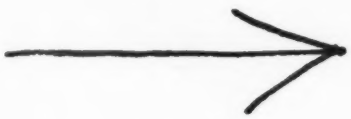

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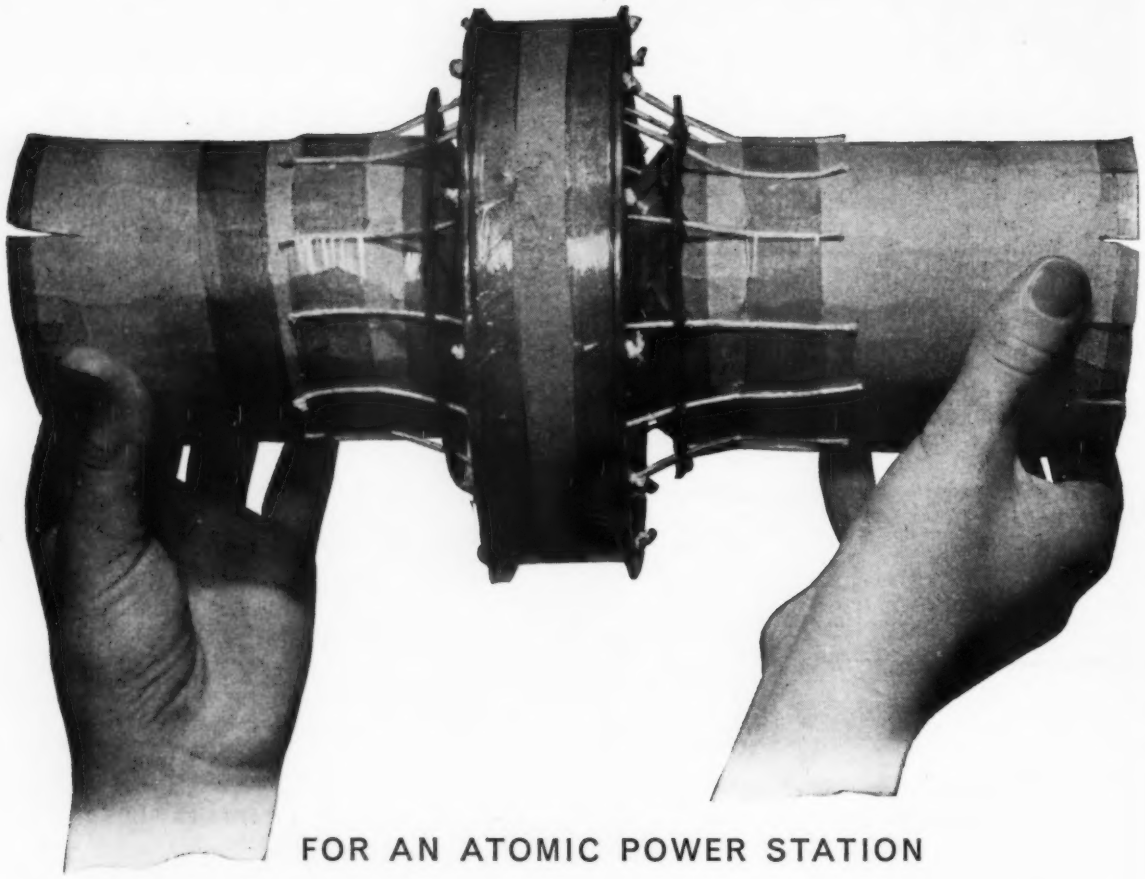
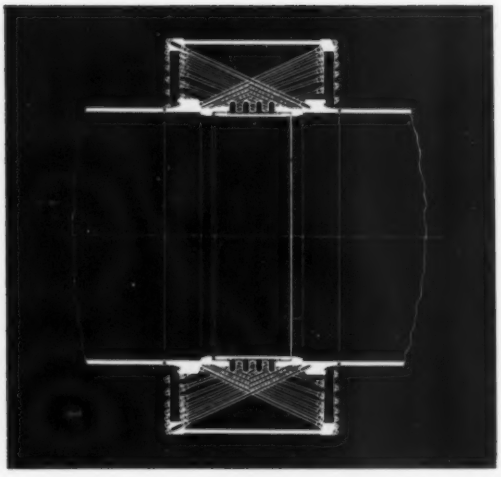


FOR AN ATOMIC POWER STATION



Don't despair if you cannot immediately follow the functioning of the bar system. It took the Engineering Division several days to understand it, and the only way they could make it clear to our executives was with the cardboard model in the photograph.

With cardboard, string, the office sticky-tape and an artificial pearl borrowed from a typist (for the spherical joint between the two cones) Richardsons Westgarth engineers have knocked up a radically new solution to a very old and tricky problem – how to take up the expansion of large pipes carrying high pressures. The problem came into the design office in the specific form of the CO_2 ducting of the Trawsfynydd Atomic Power Station. Pressure 265 p.s.i.; temperature 420°C; axial thrust on any cross section over 1,000,000 lb.

The usual means of taking this thrust – on either an internal flexible tongue or an external arrangement of hinge pins, guides and rollers – are cumbersome and, worse, flexible in only one plane, so that any sideways deflection produces stresses incapable of analysis. Rollers and pins need lubrication and are subject to wear, and both disturb the uniform distribution of stress around the periphery of the pipe. In the new Richardsons Westgarth joint the end restraint is provided by a ring of high-tensile steel bars, and flexing is taken entirely by elastic stress in these bars. The joint is thus flexible in *all* directions. No lubrication is needed; all forces are calculable – and they are fed uniformly onto the periphery of the restraint.

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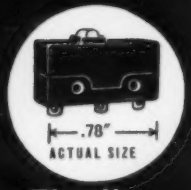

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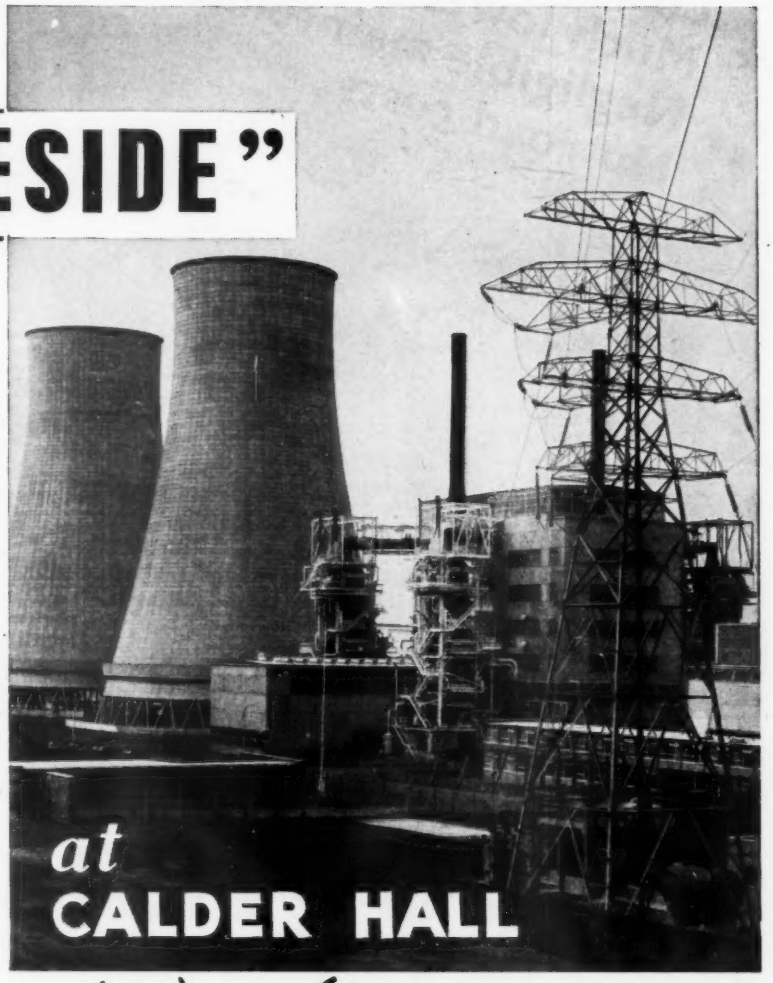

Photo by courtesy U.K. Atomic Energy Authority

With the advancement of Atomic Power, cables must play an important part in the efficiency and reliability in the production of Nuclear Energy. Only the best is good enough and Wandleside Cables are eminently suitable.

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and a very high degree of efficiency and reliability

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HDO Fuel Oil Valve. Size ⅛"—⅜" B.S.P. Low pressure, minimum pressure drop.

ST/2/B Straight Through in-line Valve. Air, gas or light oil. Pressures up to 100 p.s.i. Size ¼", ⅜" B.S.P.

DPS MKII Differential Pressure Switch. Standard pattern. Range 0-30" w.g. 30"-10 p.s.i. Details of high static and high differential models on request.

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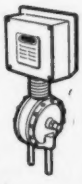
VHPS High Pressure Switch. Fully adjustable, piston operated. Pressure range up to 10,000 p.s.i.



DPS MKIV Differential Pressure Switch. Stainless steel construction specially designed for Nuclear Power Stations. High static, high temperature. Medium CO_2. Pressure 300 p.s.i. Temperature 250°C.

BA3

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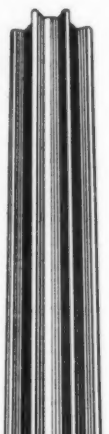

Designers have a habit of asking for the impossible, but in a surprising number of cases Accles & Pollock produce an answer that enables the production people to translate the concept on the drawing-board into a physical, functional form. Accles & Pollock welcome all such opportunities to co-operate in developing new applications in the form of tubes and tubular sections.

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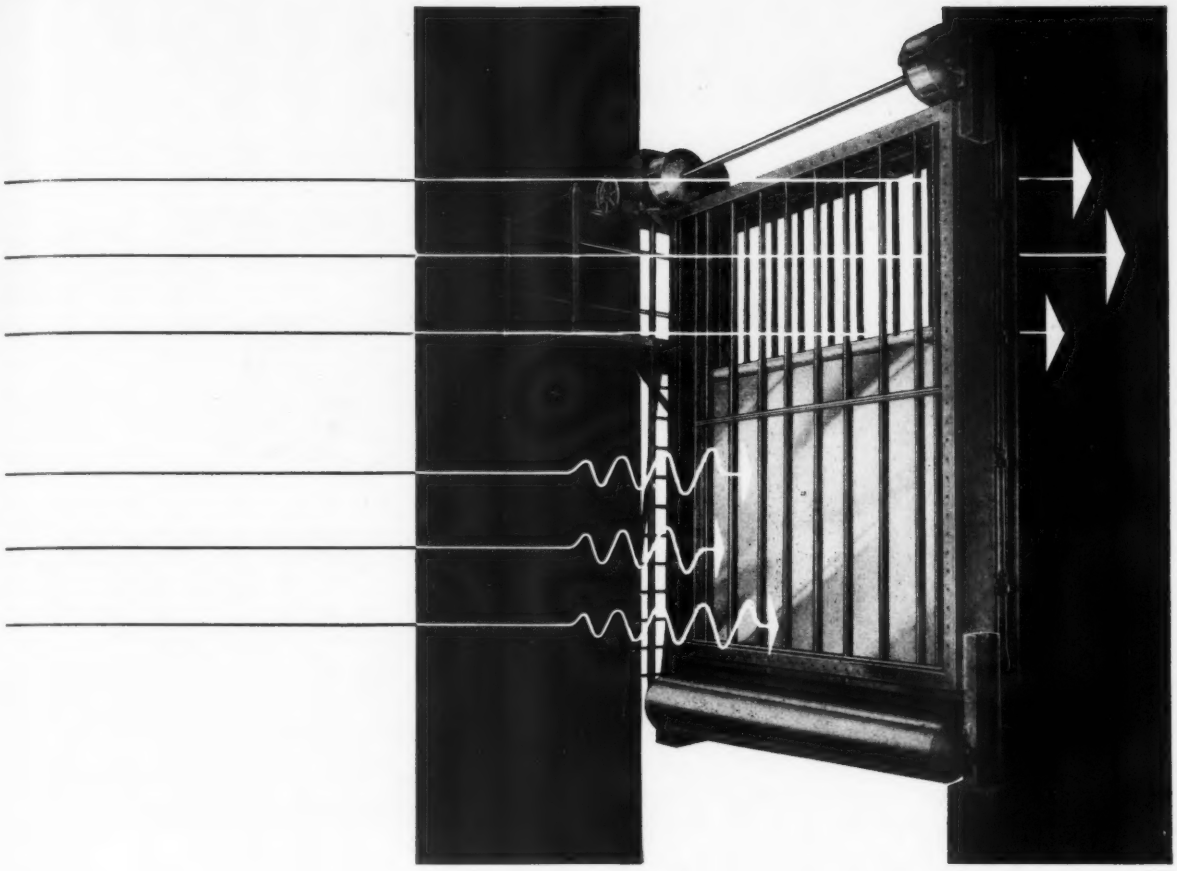
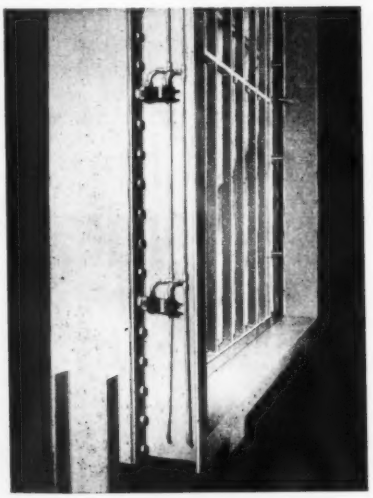


The Dowling Damper



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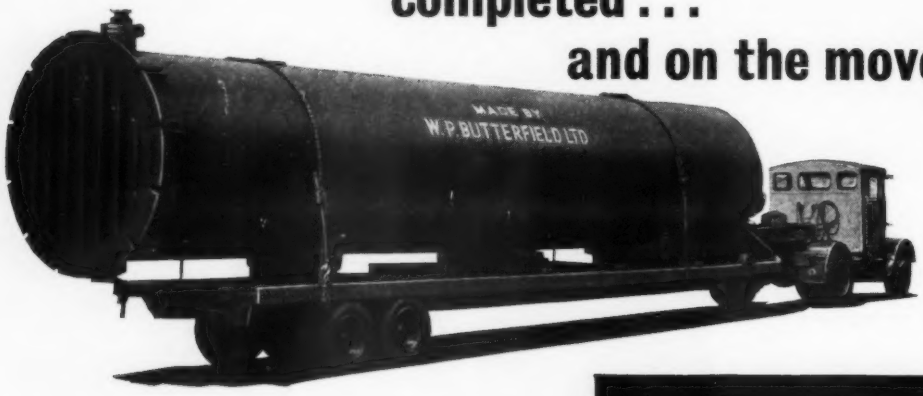

Our illustration shows a Vertical Alkylation Reactor, 7′ 6″ I/D by 45′ 8″ overall height, fabricated from ⅜″ thick Mild Steel B.S.14 plate, having a welded dished and flanged top plate and a ½″ thick bottom plate, stiffened with 10″ x 5″ rolled steel joists. All flanges on the vessel are lined and faced with Hastelloy " B ".

Design pressure: 28 p.s.i.g. at 300°F. Working pressure 2·8 p.s.i.g. at top of vessel at 210°F. Hydrostatic test pressure: 42 p.s.i.g. Vessel spot radiographed

MILD STEEL PLANT

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fabricated to the exacting demands of the Nuclear Engineer by

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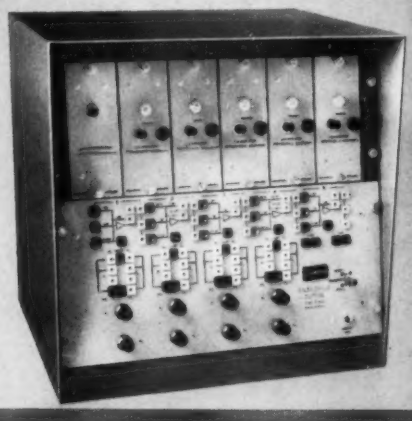
1 analogue tutor

Capable of demonstrating any form of second-order differential equation. Applications include representation of servos, simple electrical networks, motion of particles and like systems.

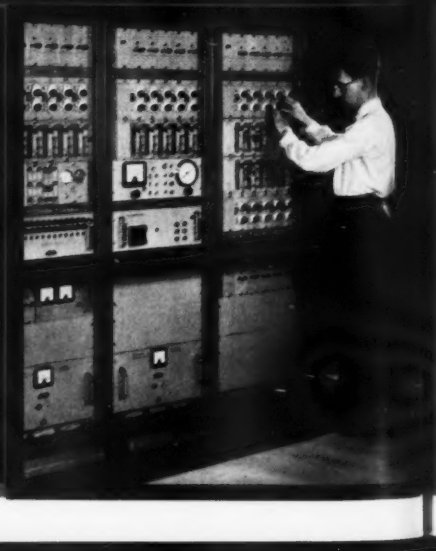


* A complete miniature computer for Student use

It is safer and cheaper to simulate mistakes than make them. Without having to build it, here is your projected system brought to your very desk-side or laboratory!

The Solartron SPACE '30' analogue computer (right) is unique in flexibility of application. With an operational capacity greater than many computers using 40 or more amplifiers, SPACE '30' has an additional problem-beating complement of non-linear units for direct analogue simulation of almost any dynamic system. Even when many complex system elements must be included as analytic or empirical non-linear operators, SPACE '30' will faithfully simulate according to the known information to produce a highly accurate prediction of dynamic performance.

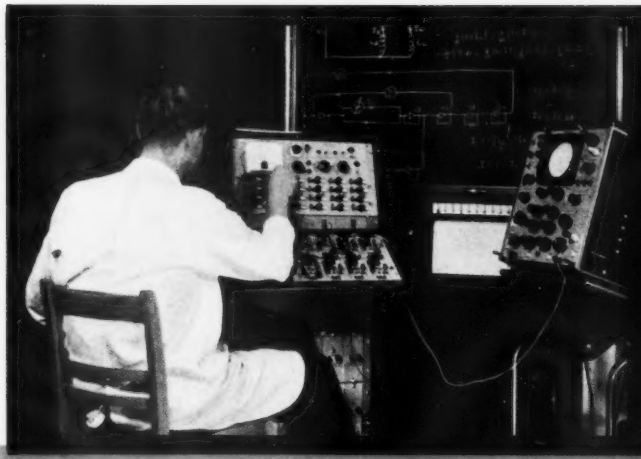
All Solartron analogue computers are built using a highly flexible modular construction technique. Thus at any time, your Solartron machine need only be as complex as budget and work demand. Special machines, like the Auto-Control Simulator illustrated here, or the SPACE '30' series, can be expanded or multiplied at a moment's notice.



ANALOGUE COMPUTERS

The Analogue Computer is the foremost aid to training in feedback techniques and theoretical servo analysis, also for clearly representing and solving complex differential equations.
Because of its common basic approach to all dynamic problems, analogue computing practice is vital to broadening engineering appreciation. Parallels between widely different systems are drawn with sudden lucidity — between hydraulic controls and national economics for example, or between a nuclear reactor and a controlled biological culture. Every problem solved on an analogue computer brings a wealth of dynamic knowledge, relevant to wide areas of subsequent work.

MINISPACE * Provides high accuracy at low cost * Ideal for servo simulation and basic reactor studies for students. * Eminently suitable for sub-programming larger machines.



2 minispace

★ Solves linear or non-linear problems: up to 5th-order differential equations.

★ Easily expanded to greater problem capacity.

For handling even bigger problems, your SPACE '30' installation can be multiplied to give 60 or 90-amplifier capacity—or, in the preferred case, you can choose a SPACE '60' or SPACE '90' machine, each fully integrated for centralised programming and control.

3 space '30'

★ 30 amplifiers in new, optimised design configuration.

★ Full complement of non-linear computing elements.

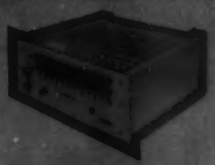
★ The first choice for complex dynamic simulation of any kind.

★ Easy to use — easily expanded.

FOR INDEPENDENT USE

These three Solartron Analogue Computing Units are typical of many which exist in their own right as precision instruments and which are immediately available for use independently, or in existing analogue computing installations.

Full technical literature is available on request.



- 12-Segment, high accuracy function generation. ± 100 V output, 0.5% long-term stability.
- Rapid, accurate break-point setting in Cartesian co-ordinates, by digital volt-meter.

5 diode function generator TR 829

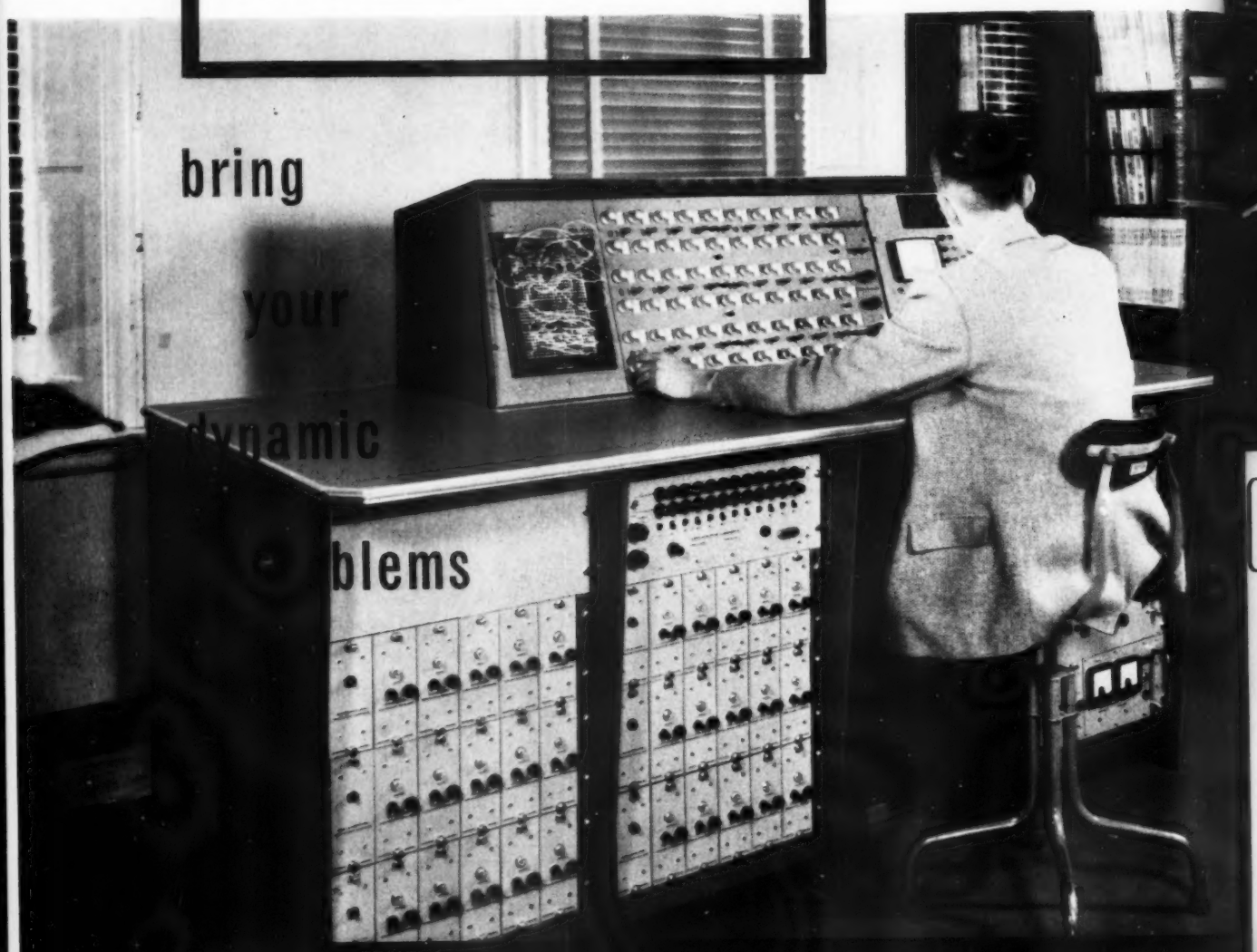
- Fastest response available: accurate r.s.d. up to 10 c/s.
- Six-section pot, driven directly from servo.
- Self-contained with transistor feedback amplifier and power supply.
- Multiplies up to five variables by one other or generates up to sixth power.

6 servo multiplier TJ 725

- 0.005% limit on deviation between positive and negative 100V supplies. NPL certificate on request.
- Better than 0.1% long term accuracy and 4,000 to 1 stability ratio.
- Incorporates Weston cell as reference source.

7 precision reference power supply AS 756/2

THE SOLARTRON Computer Centre at the Dorking Research and Development Laboratories of the Solartron Group offers comprehensive facilities for dynamic problem evaluation, programming and detailed solution on SPACE '30' Analogue Computers. Skilled personnel will, if you require, translate your problems into computer language and carry out all the operational procedures.



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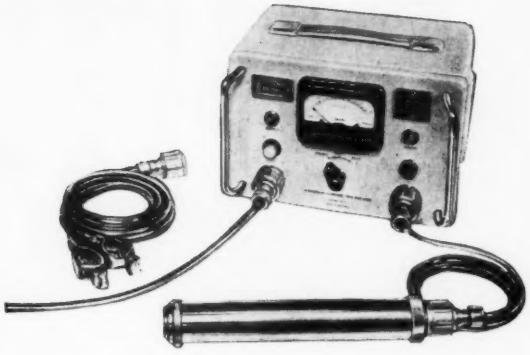
Growing acceptance of the radiation monitor and detector devices developed by Plessey Nucleonics Limited establishes their overall superiority. Indeed, the PNL instruments illustrated here offer substantial improvements of robustness and convenience of application over the type available hitherto.

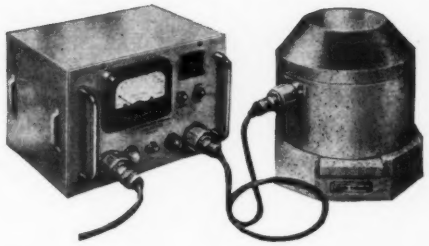


Selective Gamma Monitor type 1080
—Publication No. PNL 111

PNL programmes for nucleonic development

PNL is engaged in the design and manufacture of standard and specialised nuclear instrumentation—burst fuel element detectors for reactors, flux scanning equipment, radiation detectors of all types, process control instrumentation, health and defence instruments.

The parallel production by PNL of so much that is complementary in nuclear instrumentation has established within the Company a unique bank of scientific skills and techniques, which is now offered for the development of new projects. The Company's liaison engineers are freely available to assist with problems in their field.



General Purpose Contamination Monitor type 1065
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will amalgamate the four Canadian uranium mining companies under Rio Tinto's management to form the largest uranium producing company in the world.

Thorium Limited, UNITED KINGDOM
owned by Rio Tinto and Dow Chemie A.G., processes crude thorium materials and markets a variety of refined thorium and rare earth compounds.

Mary Kathleen Uranium Ltd, AUSTRALIA
managed by Rio Tinto in Australia, is now in full production and supplying uranium oxide for Britain's nuclear power stations.

Nukem-Nuklear-Chemie und-Metallurgie G.m.b.H., GERMANY
has been formed by Deutsche Gold-und Silber-Scheideanstalt (Degussa), Rio Tinto and Mallinckrodt Chemical Works to manufacture nuclear fuel materials and fuel elements.

Rio Tinto Dow Limited, CANADA
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Austro-Chematom Kernbrennstoff G.m.b.H., AUSTRIA
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Rio Tinto Management Services (U.K.) Limited
BARRINGTON HOUSE, 59 GRESHAM STREET, LONDON, E.C.2

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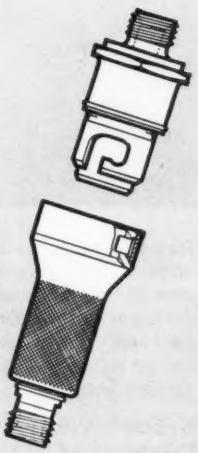

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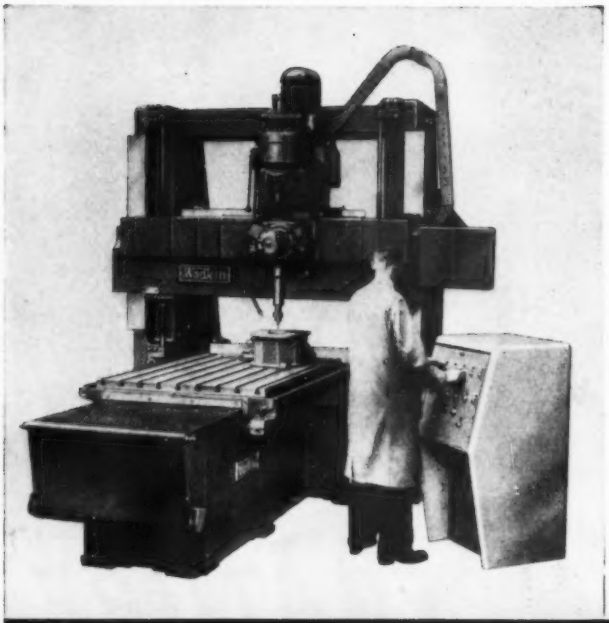

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Most advanced of their kind -used throughout industry.

Rotax Recirculating Ball Threads are over 90 per cent efficient. All ball threads and nuts are completely reversible, but locking devices can be supplied if required. Stabilised and made of special materials, they remain accurate indefinitely. 'Clean' nuts simplify fitment.

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Operating load.....up to 80,000 lb.
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Standard Pitches.....·200″ ·218″ ·250″ ·500″
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(using special materials, temperature range can be extended up to +950°C.)

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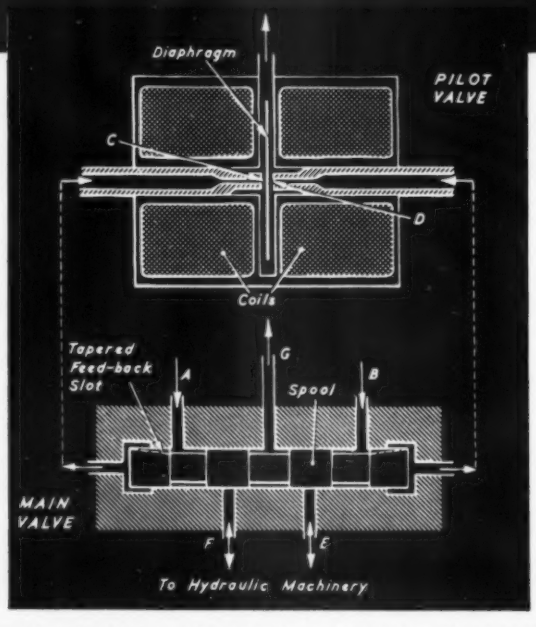

The valve — see diagram — consists of a main valve and a pilot valve. The main valve is supplied with pressure oil through ports A and B. When the spool is in the central position — as shown — the oil escapes through the tapered slots to the opposed jets C and D in the pilot valve and impinges on each side of the diaphragm. The two coils can be energised to attract the diaphragm towards one or other of the jets. If the signal to the right hand coil is the stronger, the diaphragm will flex to the right, restricting the flow from the right hand jet and thus increasing the pressure in that line. Similarly, the pressure in the left hand line is reduced. This pressure difference is transmitted to the main valve and causes the spool to move to the left until the resultant decrease in discharge area of the tapered slot at the right hand end of the spool and the increase in that at the left cause equilibrium to be restored. The displacement of the spool uncovers ports E and F, thus opening pressure and return lines to the hydraulic machinery.

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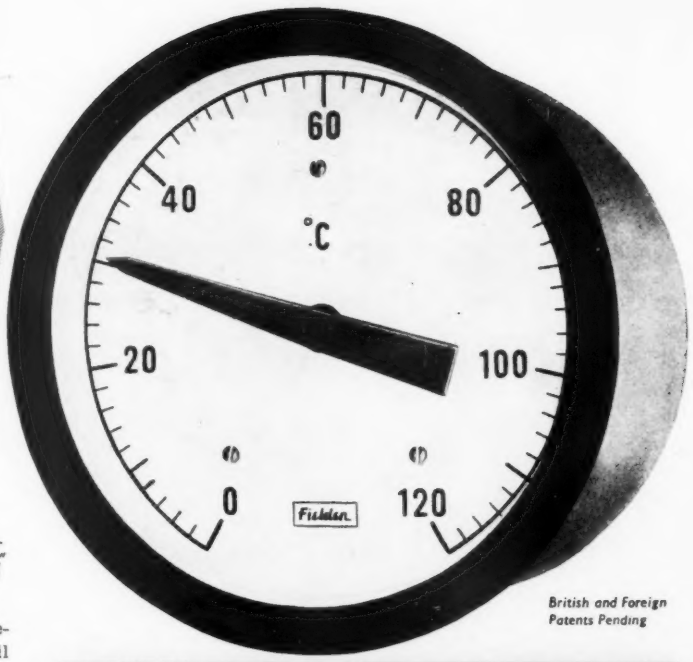

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VERY ROBUST. Sealed 6" diameter instrument, with measuring bulb in ¼" diameter stainless steel sheath.

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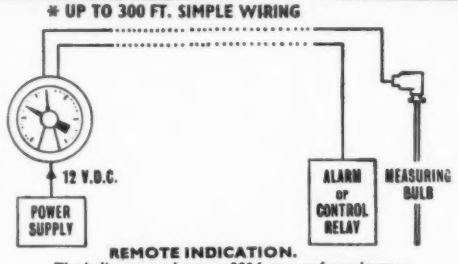

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The Indicator can be up to 300 feet away from the measuring point with no effect on calibration and accuracy.

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The Indicator can be supplied with an adjustable control contact for use with local or remote alarm or control relay.

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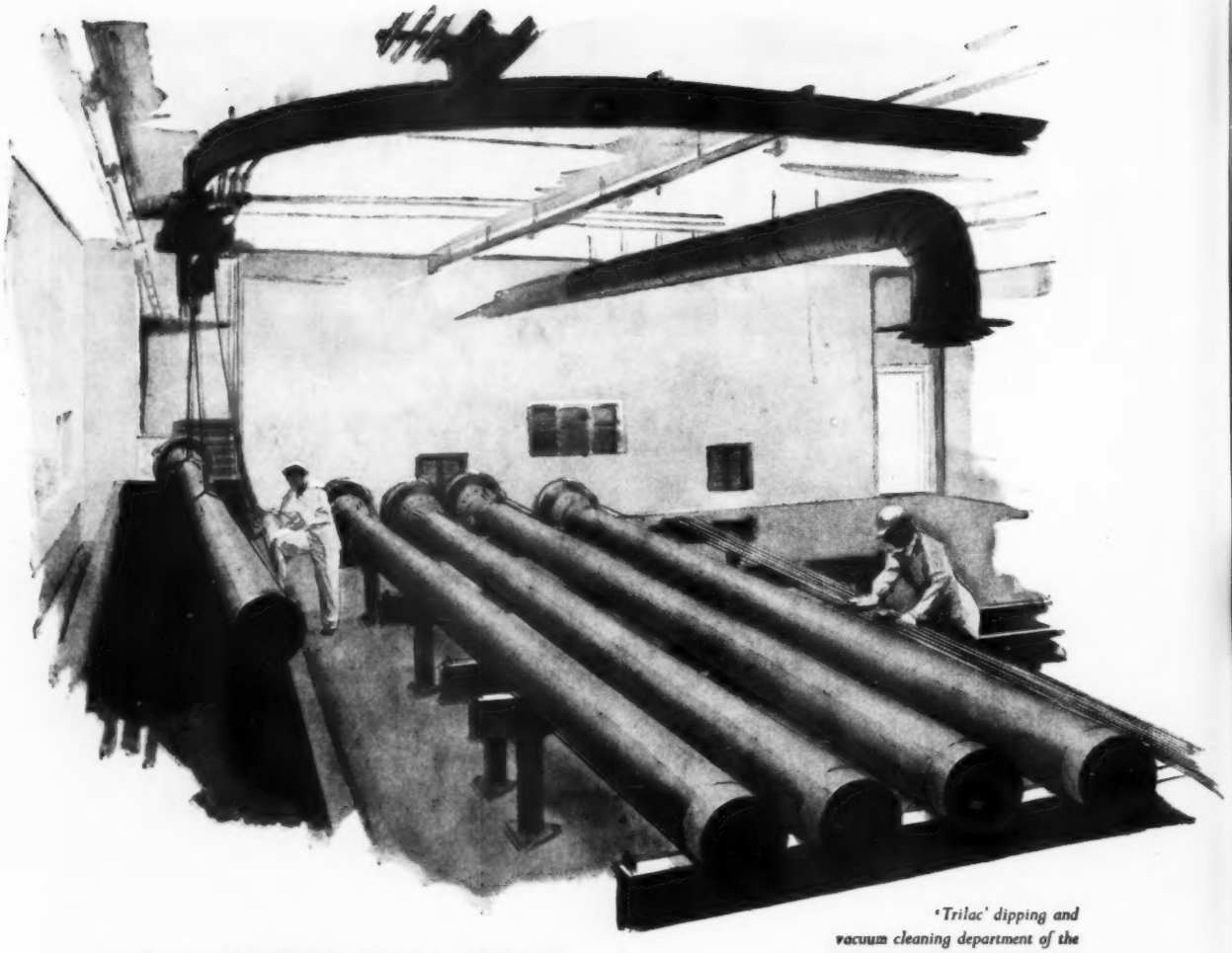

'Trilac' dipping and vacuum cleaning department of the 'CLEAN CONDITIONS' PLANT

S & L PIPEWORK FOR BRITAIN'S NUCLEAR POWER STATIONS

It is becoming general for many components for nuclear plants and other forms of construction to be assembled under entirely dust free conditions.

To meet the requirements of the nuclear age S & L have constructed a special 'clean conditions' plant at their Tollcross Works in Scotland. This new plant is probably the largest and best equipped in industry and comprises many important features, including fully filtered and heated air, a large assembly area, together with cleaning and protection facilities.

An example of the work assembled in this shop is the control rod standpipes for Hunterston nuclear power station. The standpipes shown in the illustrations accommodate boron rods and house the small bore burst slug detection piping.

S & L will be pleased to discuss any problems associated with clean conditioning of industrial components.

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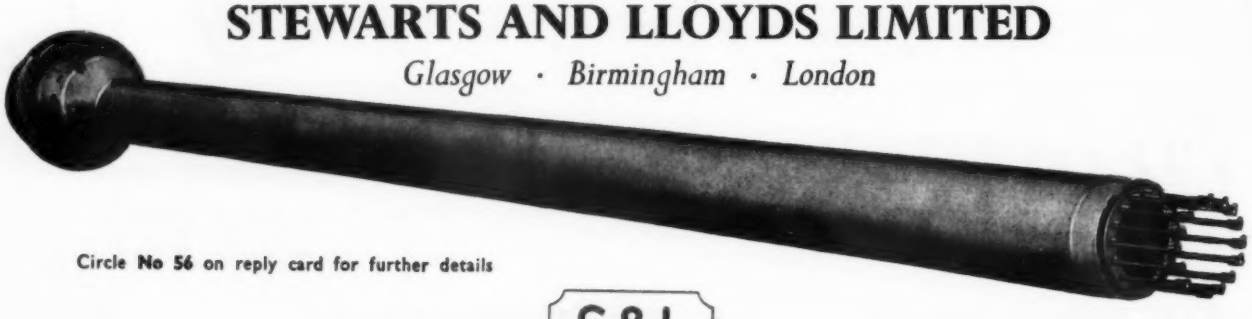

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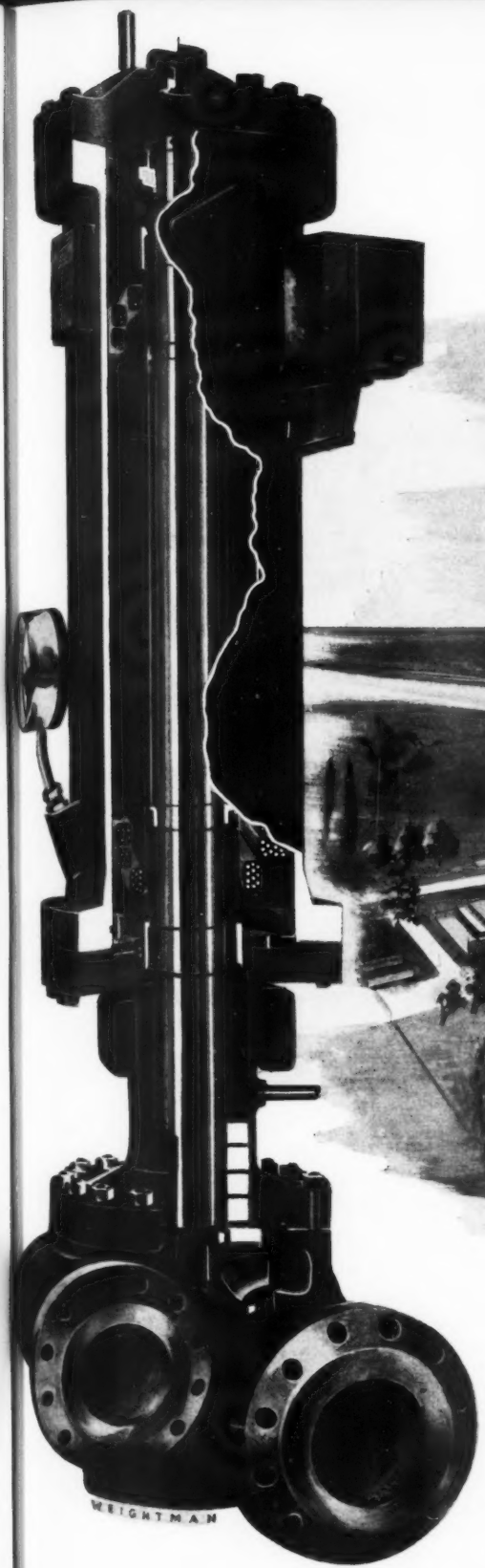
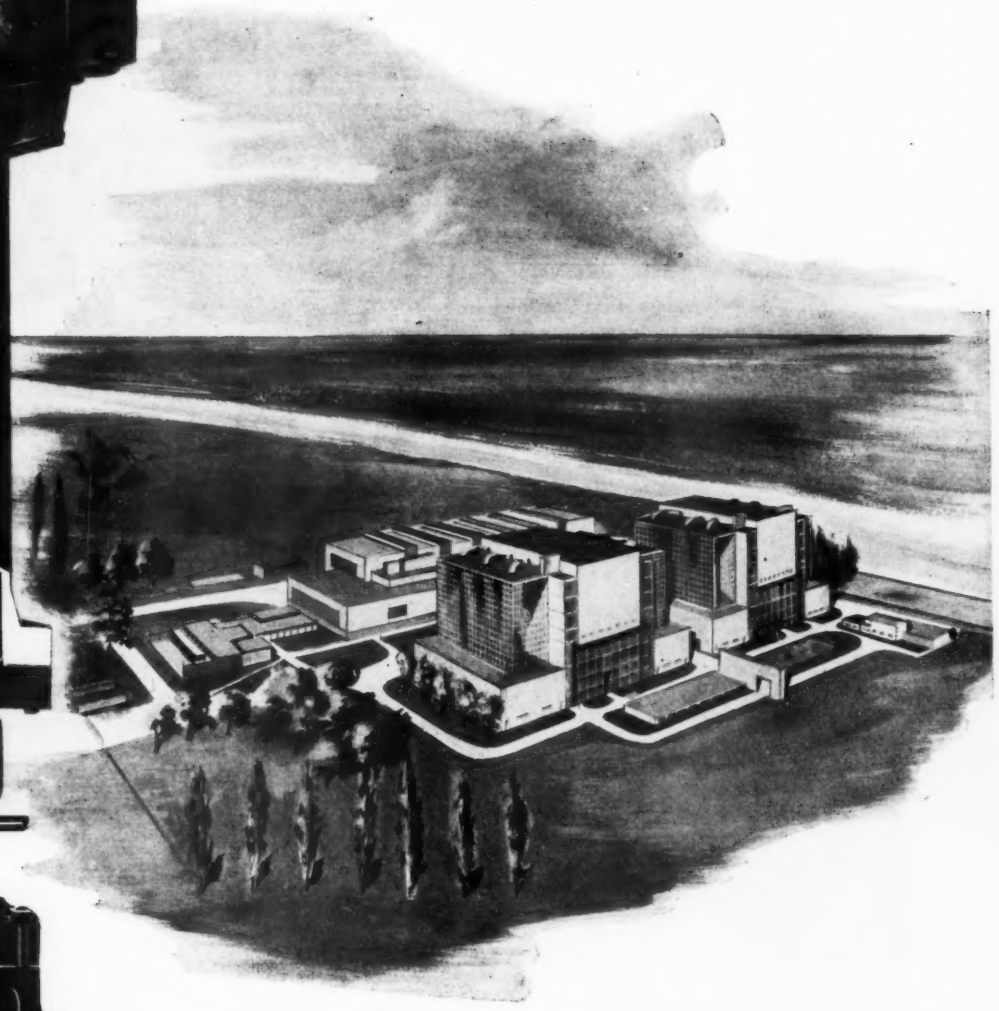
S&L





Hayward Tyler Glandless Electric Motor Pump Units are at work in Nuclear Research Establishments, Nuclear Power Stations and high pressure boiler installations in the following countries: AUSTRALIA, CANADA, DENMARK, FRANCE, GERMANY, INDIA, ITALY, JAPAN, NORWAY, SWEDEN U.S.A.

In BRITAIN they are installed at, or on order for, Harwell, Capenhurst, Windscale, Risley, Calder Hall, Chapelcross, Dounreay, Bradwell, Berkeley, Hunterston, Hinkley Point, Trawsfynydd, High Marnham, Thorpe Marsh and Blyth "B".

Nearly 600 of these zero leakage pumps have been produced.

HAYWARD TYLER

& CO LTD LUTON, ENGLAND. LUTON 6820

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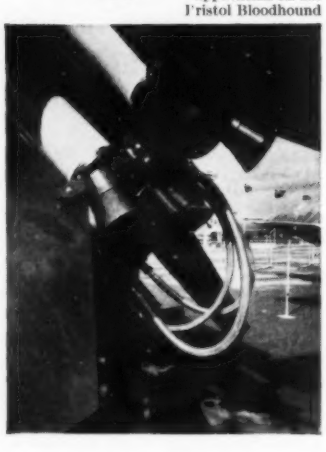
Safe Conduct

A PLESSIFLEX application on the Fristol Bloodhound



Tough, flexible, seamless, all-metal PLESSIFLEX is the most thoroughly reliable means of conveying fuels and chemicals—whether they are gases or liquids, very hot or very cold, corrosive or inflammable—from one place to another. And this point is overwhelmingly endorsed by engineers in the aeronautical, nuclear, marine and chemical industries.

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Suitably braided for stability, the tube itself is made from material that has been subjected to rigorous pre-process analysis—everything in fact about this versatile, incredibly robust product is shaped to the ends of higher performance and greater safety in fields where such requirements are essential.

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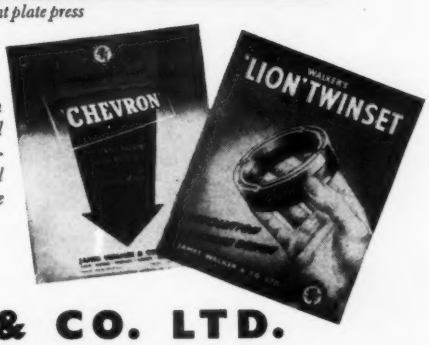
Walker's packings are used throughout a 4,500 ton hydraulic plate press at Whessoe Ltd., Darlington. Possibly the largest of its type in the world, it was designed specially for the shaping of spherical pressure vessels for atomic power stations. The pressure vessels (made from well over 1,000 tons of steel) have walls up to 4 inches thick which are pressed from plates weighing up to 10 tons.

The illustration above shows this giant plate press built by Messrs. Fielding & Platt.

Free technical literature on Walker's 'Lion' Chevron and Twinset packings, which are giving such outstanding service on all types of presses throughout the world, will be sent on request.



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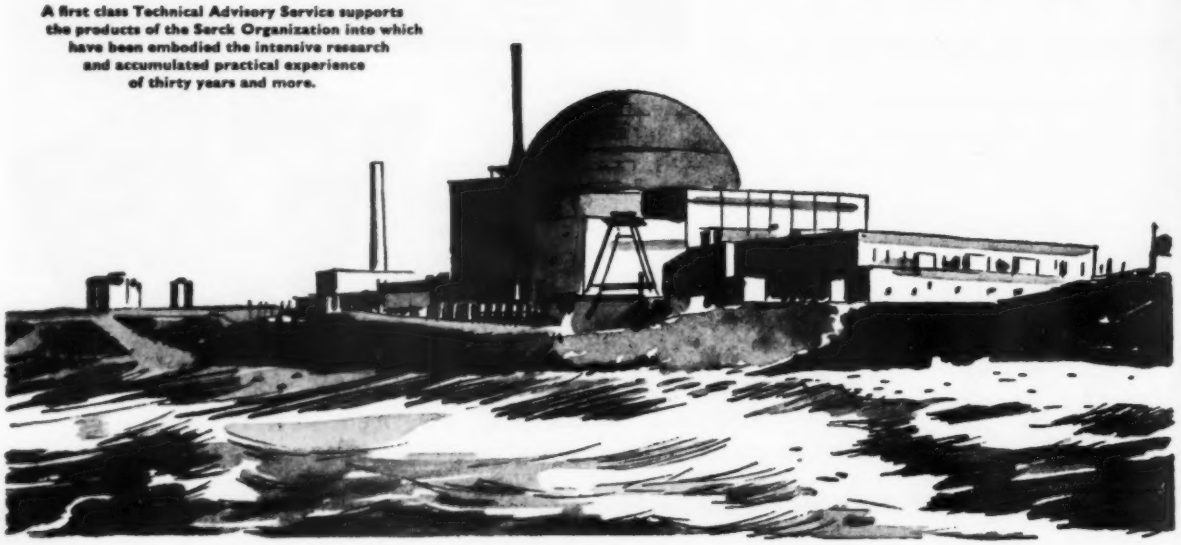

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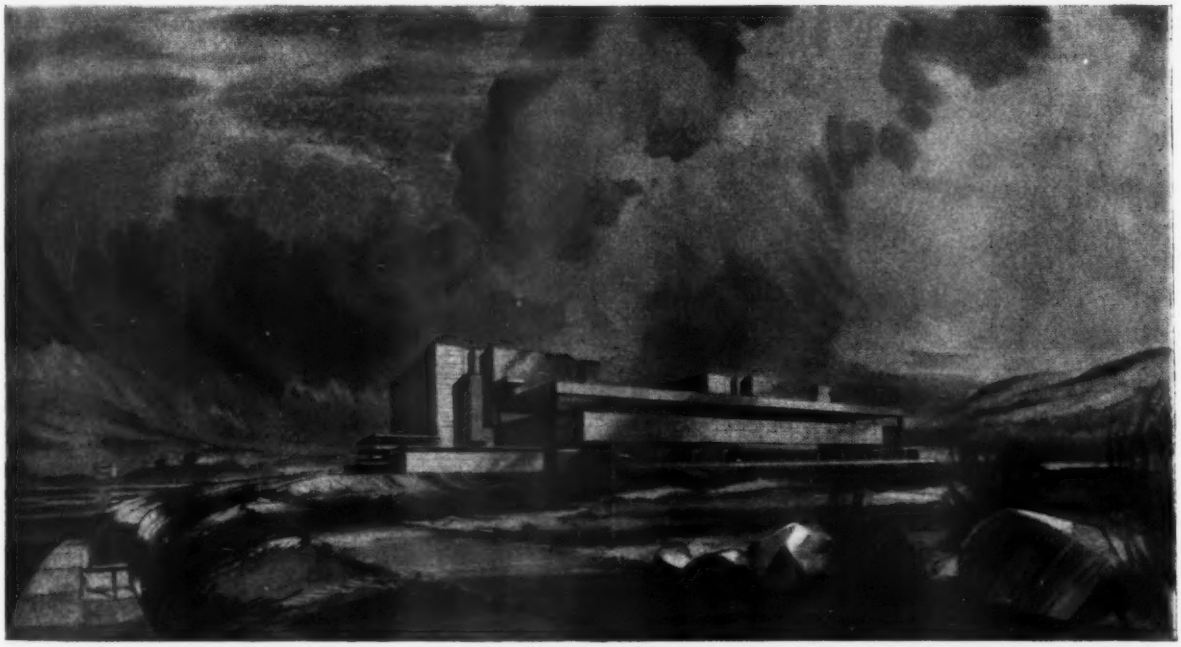
who are responsible for the design and construction

of all building and civil engineering work on

Trawsfynydd Nuclear Power Station



The 500,000 Kilowatt Nuclear Power Station at Trawsfynydd
is now under construction for the Central Electricity Generating Board by

Atomic Power Constructions Ltd. Mowlem Construction Co. Ltd. Parkinson Ltd., Fairey Aviation Ltd.,
International Combustion (Holdings) Ltd., Wolverhampton Metropolitan & Vickers Ltd.

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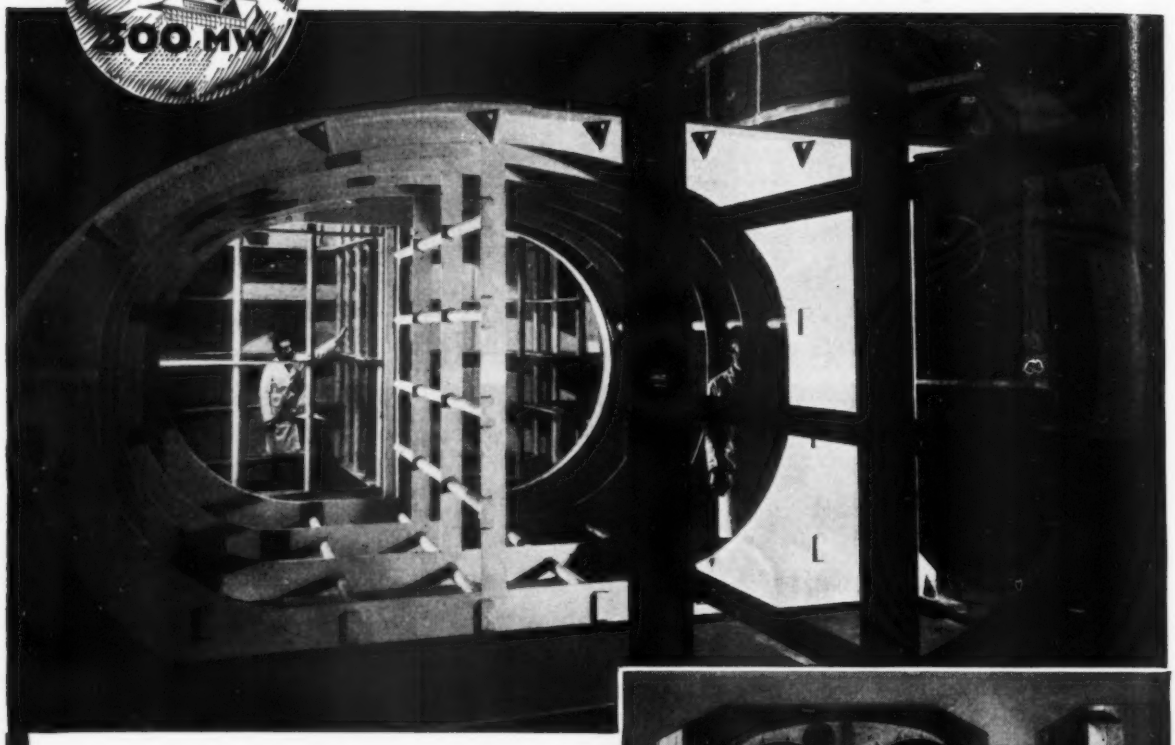
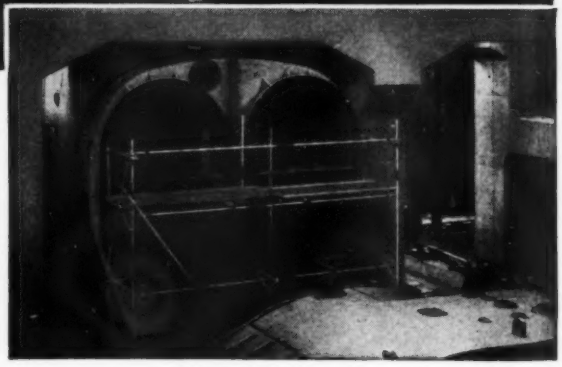
HINKLEY POINT

operation PROGRESS



Rapid progress is being made at the Hinkley Point 500 MW atomic power station now under construction for the Central Electricity Generating Board. On schedule, too, at the works of The English Electric Company is the building of the 6 main and 3 auxiliary turbo-alternator sets and ancillary equipment.

Here, at the 'English Electric' Liverpool Works, condenser body quadrants are being inspected prior to assembly and shipment to Hinkley Point, where the complete condensers are being erected in the 740 ft. long turbine hall. Each unit, comprising two condensers, will contain 81 miles of tubes and is designed to deal with 355 tons of steam per hour.



For stations of similar type for construction overseas, designs can be offered through a range of outputs from over 500 MW to 100 MW or below.

ENGLISH ELECTRIC

THE ENGLISH ELECTRIC COMPANY LIMITED
English Electric House, Strand, London, W.C.2

BABCOCK & WILCOX

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Nuclear Power
REACTORS MATERIALS INSTRUMENTATION PROCESSES IRRADIATION
NOVEMBER 1960 VOLUME 5 NUMBER 55

VIEWPOINTS *letters to the Editor*

Canadian steam cooling plans

SIR: We were pleased to see you take note (*Nuclear Power*, September 1960, p. 116) of Canada's interest in steam cooling. May we bring your readers up-to-date with our plans for this phase of the programme of Atomic Energy of Canada Limited.

When we first looked at steam cooling we considered a one-pass reactor (i.e. the SCHW system). At the same time we asked Orenda Engines to design a loop for the NRU reactor that could be cooled with superheated steam. Our calculations subsequently showed that the SCHW system, even with optimistic assumptions about the development of new materials, would not be a competitor to the CANDU reactor (our D_2O-cooled 200 MWe reactor) now being constructed for operation in 1964. We thus dropped our work on the SCHW system and will not be taking any action on the Orenda design that you described for a steam-cooled loop in NRU.

The steam-generating reactor, a two-zone system, seems a more likely rival for CANDU and we are cooperating actively with the UKAEA Industrial Group in this concept. For instance, one of the water-cooled loops in the NRX reactor at Chalk River is being converted to steam-cooling (operation planned for spring 1961) for the UK to test fuel for steam-cooled systems.

We are also interested in fog cooling, i.e. wet steam that does not become saturated in its passage through the reactor. Orenda Engines are now considering a fresh design of a steam-cooled loop for NRU that would handle more varied steam conditions and in particular could use fog cooling. We have, however, no plans yet to build such a loop in NRU.

Vice-President, W. B. LEWIS
Atomic Energy of Canada Ltd

Training reactors

SIR: A letter by Mr. H. Montgomery (August 1960) encourages my partiality for training reactors of the swimming pool type. However, economical design for this type of reactor has not been seriously considered.

Particularly in connexion with the design of swimming pool components, the importance of simplicity and conventional techniques increases as budgets begin to shrink. One case which can be profitably examined is the design of rolling bridge structures in pool type reactor facilities.

The basic requirement of the bridge structure is to carry the reactor core and its support structure conveniently from one position to another. The corollary requirements are: adequate support, with little or no deflection due to movement of personnel on the bridge; stability against the overturning moment imposed by a heavy core suspended at one edge (without recourse to heavy weights); ability to move smoothly to an accurate, reproducible position in any part of the pool; minimum free play between the rail and wheels, and between wheels and bridge; minimum of mechanical parts is desirable; bridges require interlocks for high power, low power, and shutdown, as well as fail safe electric brakes; minimum bulk and weight.

The conventional reactor support structure is a rather massive bridge, wheeled, provided with gears and a crank, a double platform, automatic brakes, interlock switches, lubrication means, and a boarding ladder; positioning bumpers are provided at each end of the pool.

Let us discard, however, the idea that wheels are indispensable for motion; in one simple step, fitting slippers instead of wheels, we can immensely simplify the whole mechanism. The bridge is then supported on one side by two V blocks riding a V rail, and on the other side by two flat slippers riding a flat rail. In one step we have abolished wheels, axles, bearings, cranks, gears, brakes, and have drastically reduced height and weight. Shifting of the bridge is accomplished by the use of a cable and capstan at either end of the pool. Consider how the requirements are served by the simplified design: 1 & 2. The slippers can readily be placed at the extreme corners of the bridge, thus reducing any overhanging moment to practically nothing. With no wheel height to consider, a double platform arrangement can be made low and compact. The main supporting member may be a simple straight beam, very rigid. 3. Movement will be smooth and accurate; the V rail will absolutely position the structure transversely; longitudinal positioning is assured by inserting a stop rod through the bridge beam into a socket fixed to the pool structure. 4. There is no free play anywhere in this system. 5. Having abolished mechanical complexity, we can simplify safety features also. The lock rod described in (3) above, will operate the high power, low power, and off switches, depending on the depth of the socket into which it is inserted. There is no need for a brake or safety switch in connection with it. Once the pulling cable is unsnapped, nothing can disturb the bridge positioning. End stops are not required. 6. The elimination of wheels makes possible a reduction of several feet in height, eliminates side overhang, and improves access.

Another case in which conventional practice may be improved, and at a lower cost, is in the incorporation of cooling provisions. Conventional forced cooling systems applied to movable cores are complex and expensive. A simple approach is to cool the pool water, instead of adding a forced circulating system to the core. A conventional refrigerating system may be applied to cool the pool water to any reasonable temperature, say 70°F, which would not produce undue thermal shock to any part of the system, and would not unduly affect core design. The immediately apparent advantages are: 1. A better thermal head; 2. Less water is required; 3. Much better control of water temperature is achieved.

The core designer will be grateful, since the cooling problem now becomes a smaller percentage of his design considerations. The plant designer will have a simple uncomplicated chilling system, instead of a complex forced circulating system.

Kaiser Engineers, P. N. GARAY
Oakland, California

Scintillation Counter Survey

SIR: May I point out that Mr. Owen's Scintillation Counter Survey in your October issue omits the information that we are the UK agents for Allen B. Du Mont Laboratories (USA).

G. O. STRATTON-BROOK

Aveley Electric Ltd.,
South Ockendon, Essex

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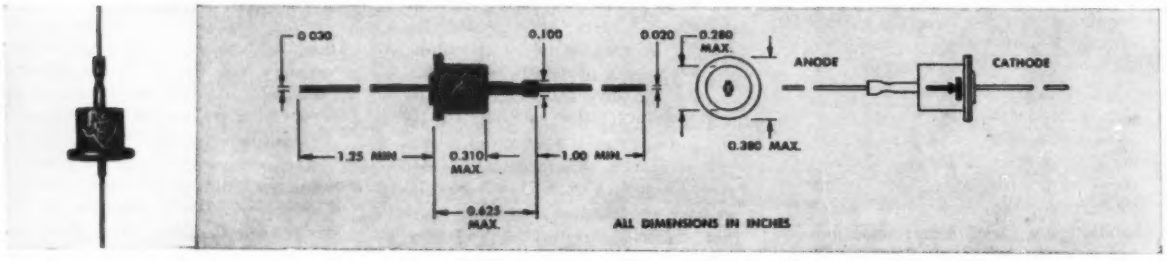
Recurrent Peak Forward Current at +25°C ...	i_l	2·5	2·5	2·5	2·5	A
Surge Current, 1 cycle at 60 c/s at +25°C ...	I_{pk}	15	15	15	15	A
Operating Temperature, Ambient	T_{amb}	——	−40 to +100	——		°C



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OPINION

Difficulties overcome

LOOKING AT THE construction programme of the CEGB stations and also the design changes made necessary by new discoveries (see pp 74–86 this issue), it is impossible not to be impressed by the size of the task in hand. A tight schedule is being followed in the face of many difficulties, some of them man-made, but most arising from having to work on concepts that are simultaneously undergoing proving tests.

Excluding the labour problems—these crop up in any major industrial endeavour—and the difficulty of getting the hundred and one sub-contractors to co-ordinate their efforts, some changes have been necessary, brought on, for instance, by more information on graphite behaviour and fuel element performance (see *Worldview*, this issue). It is to the consortia's credit, therefore, that they have been able to overcome these difficulties and it is interesting to note how different teams have gone about similar jobs in different ways but with the same basic considerations.

With the ever increasing emphasis on accomplishing the transition to competitive nuclear power and the need to develop other reactor types (shared reluctantly by the authorities here), Mr Robert McKinney's comments in his latest report to the Joint Congressional Committee on Atomic Energy are particularly sobering. ' Unless programmes in North America and Western Europe for the construction of advanced type atomic power-plants are expanded, the number of experiments and prototypes necessary to accomplish the transition to economically atomic power are unlikely to exist until well after the 1970's ', he says.

But as far as British efforts are concerned, the CEGB's fixation on gas-cooled graphite moderated reactors and on size as a way of cutting costs, has necessarily tied up our nuclear engineering effort. The result is that the consortia have little time and effort to spare to think about advanced designs. Even where they have been interested in the AGR, there have been complaints that the AEA have not been as forthcoming with information as they should be. The argument that no further magnox stations should be built after Sizewell and an investment made in other power prototypes is becoming more and more attractive and sound.

Future prospects of cheaper enriched uranium may well prove the point and direct efforts to the development of concepts with smaller cores, leaving Britain and France with nuclear power stations that no other country in the world wishes to buy.

Export policy

THE REALISTIC ATTITUDE towards exports taken by leading executives in reply to our questionnaire (see pages 90–91) again turns the spotlight on the Government and the AEA, whose conservative attitude is in sharp contrast. Our questionnaire shows that little or no immediate short term exports are envisaged; in the long term, better prospects are seen but the need to develop new reactor types rapidly is stressed as is some form of official encouragement.

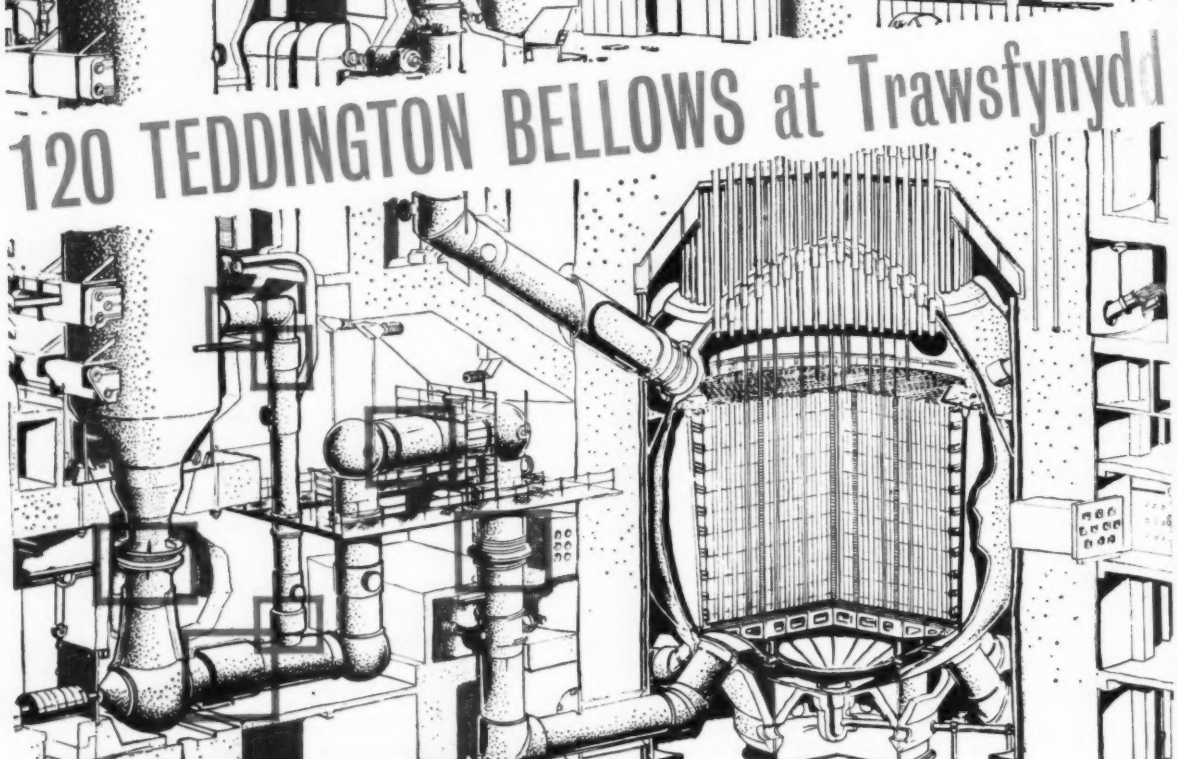
So far there has been no worthwhile official energy policy—what exists is muddied and shifting; still less is there an export policy. It is time a clear directive was issued which avoids such terms as ' a deferment of acceleration '; about time, too, that the Government and the AEA looked seriously at this question of exporting nuclear power stations and of developing new types of reactors for export. Most of the replies to our questionnaire, for instance, refute the AEA's views on small reactors.

Are we to export reactors or not? If so, then some encouragement is needed for our under-employed industry. Bumbledom should give way to recognition that the nuclear industry can play a significant part in Britain's export drive and that muddled thinking such as that displayed by one responsible AEA official, quoted in a reply to our questionnaire, that they (the AEA) were not concerned with encouraging export sales, should certainly be refuted.

In addition, manufacturers who have paid some attention to other reactor types should be provided with some encouragement; fuel element prices and guarantees should be firm; thinking on ' small ' reactors (see Leader's article, p 97) by the AEA should be re-oriented to take into account that to a manufacturer, the number of plants ordered is more important than the total power ordered; if nuclear plants are at present being ' over-designed '—a not unusual happening with a new process—then designs should be simplified as soon as experience is gained; more effort should be made in getting down costs of long life fuel elements and research should be diversified to take into account, promising reactor systems.

The ' wind of change ' that is blowing in other parts of the world is all very well; a similar clear, bracing blast is apparently needed here to shift the cobwebs away from misty ministerial minds.

120 TEDDINGTON BELLOWS at Trawsfynydd



By courtesy of 'NUCLEAR POWER'

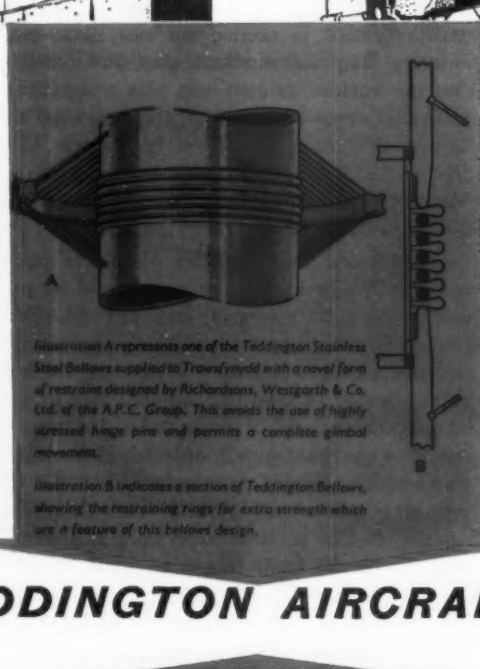


Illustration A represents one of the Teddington Stainless Steel Bellows supplied to Trawsfynydd with a novel form of restraint designed by Richardsons, Westgarth & Co. Ltd. of the A.P.C. Group. This avoids the use of highly stressed hinge pins and permits a complete gimbal movement.

Illustration B indicates a section of Teddington Bellows, showing the restraining rings for extra strength which are a feature of this bellows design.

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WORLDVIEW

the month in atomic energy

EUROPE

Bradwell fuel element production starts

London Production of the modified fuel elements for the Central Electricity Generating Board's station at Bradwell has started. There is expected to be no hold-up in getting the fuel elements to the station in time for the first loading. The station's reactors are expected to go critical before the summer with full power operation in late autumn.

The modifications were carried out to overcome the problem of vibration mentioned in the AEA's sixth annual report (p 11, para 69). It was there stated that testing of the civil fuel elements had revealed 'weaknesses in design such as excessive vibration of the fuel elements in the coolant gas stream' and would enable remedial action to be taken before large-scale production was due to start. These tests were carried out during the winter of 1959/60, using the Calder Hall reactor.

The changes that were made to the Bradwell fuel elements are disclosed in an article in this issue (p. 77–79) by Mr R. D. Vaughan, Chief Engineer, The Nuclear Power Group. This says that when the first complete fuel elements were tested, it was found that aerodynamic forces were unstable and this resulted in 'severe rattling which damaged the magnesium fitments on the can'.

The article adds that it had been found that the problem could be overcome by 'applying a constant lateral force to the fuel element and this will be done on the first charge for Bradwell with a spring-loaded slipper built on to the top end fitting. Apart from this modification, it has been found necessary to stiffen the longitudinal splitters with a number of braces. This has had some effect on pressure drop in the channel but no effect on heat transfer performance'.

There have been few official statements about fuel element prospects but some weeks ago at a press conference on the CEGB's annual report, Sir Christopher Hinton, the chairman, mentioned a 'fuel element performance difficulty'. He said this meant that the CEGB might get less units from the nuclear power stations (coming into operation in 1961) than was planned. Asked to amplify this statement, Sir Christopher added that tests had shown some weakness in the fuel elements and the AEA 'is working energetically to remove these'.

The Atomic Energy Authority, asked by *Nuclear Power* for further information, stated: 'The AEA's long term faith in the fuel element performance remains unaltered. Some problems may be encountered with the first charge for Berkeley and Bradwell and these may necessitate a more rapid operation of the charge and discharge machinery than would be expected under normal operating conditions'.

The design capacity of the machinery is reported to be 50% faster than optimum performance, which means that they could cope with a rate of defective fuel elements up to an average burnup of 1500 MWd/tonne; most unofficial statements, however, take the view that present problems will be solved and the hoped for burnup of 3000 MWd/tonne achieved.

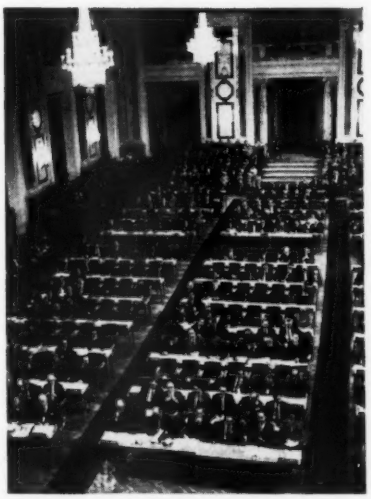
The CEGB annual report says that on fuel elements, the major aspects under study are heat transfer, pressure-drop characteristics and the length of life of the element in the reactor. Investigations are also being carried out into 'the complex behaviour of the polyzonal type of fuel element to be used in each of the four nuclear stations with the ultimate aim of increasing reactor output. Studies have also started on element designs for more advanced reactors'.

Fuel handling

Meanwhile, some recent events at Calder Hall are causing design teams to take a careful look at the arrangements for fuel handling on the CEGB reactors. *Nuclear Power* understands that cases have occurred in which the end-caps of the fuel elements were pulled off by the Calder discharge machinery; in some instances, elements have been dropped.

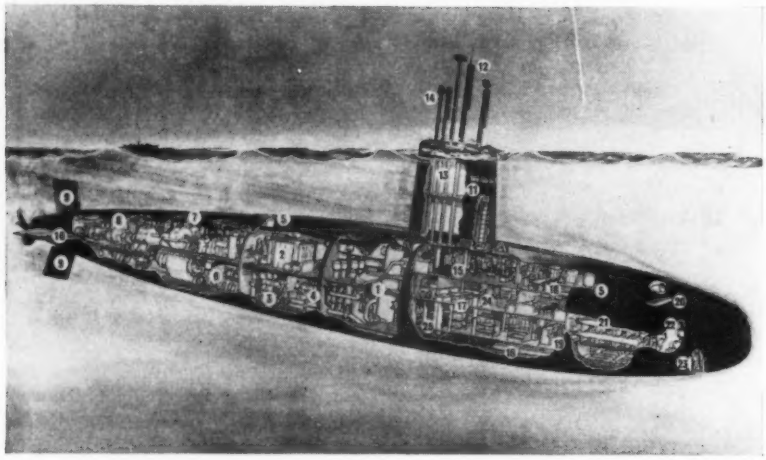
There is thus a possibility that this may happen at Bradwell and Hinkley Point, though the speed with which an element will be removed from a channel will be very much less than on Calder Hall reactors. The dropping of any damaged element would necessitate the immediate shutdown of the reactor; inspection by television camera and removal by special grabs would follow.

Unofficial statements to *Nuclear Power* emphasise that though rattle and other problems may reduce the average burnup on the first CEGB stations to considerably less than 3000 MWd/tonne with the first full loading (in fact for reasons of caution they may be programmed for a shorter life). There is no sign of any problem which cannot be overcome. The other main problem—that of dropping fuel—would, if not solved, affect the capacity of the stations to change fuel on load but here again designers are expected to find a solution to this difficulty in the near future.



IAEA CONFERENCE Delegates at the opening meeting of the fourth regular session of the IAEA General Conference at which 70 member states were represented as well as observers from the United Nations and other international organizations

WORLDVIEW



HMS 'DREADNOUGHT' A cutaway drawing of the British Royal Navy's first nuclear submarine, the 'Dreadnought,' showing: 1. Reactor compartment; 2. Reactor control compartment; 3. Auxiliary machinery; 4. Diesel generator; 5. Escape hatch; 6. Main condenser; 7. Main turbines; 8. Electric propulsion motor (alternative drive); 9. Rudders; 10. After hydroplane; 11. Surface navigating bridge; 12. Periscope; 13. Radar and radio aerials; 14. Snort; 15. Control room; 16. Electric batteries; 17. Crew's quarters; 18. Officers' quarters; 19. Electric space; 20. Forward hydroplane; 21. Torpedo space; 22. Torpedo tubes; 23. Stowed anchor; 24. Galley and 25. Store rooms and refrigeration space

Launch of first UK nuclear submarine

London The launching of the Royal Navy's first nuclear submarine, the 3500 ton *Dreadnought*, at Barrow-in-Furness, followed the visit to Portsmouth of the US nuclear submarine *Scorpion*—the first time there has been a nuclear-powered ship in any UK port with a fairly dense population.

This visit came after a further survey by the AEA of suitable ports at which nuclear-powered vessels could berth. Previously, the Authority had looked at a number of ports with a low population density. The same safety procedures—continuous monitoring and an emergency plan in case of an accident—used for *Scorpion* will probably be followed when *Dreadnought* is operating.

The *Dreadnought* itself, to be commissioned in late 1962, is equipped with an American '*Skipjack*' type pressurized water reactor which will drive a single shaft through steam turbines. Almost every electrical and mechanical part of the machinery is duplicated to minimize the inconvenience of breakdowns.

Originally, the *Dreadnought* was to have had a British-designed and built reactor but in 1958, American equipment was purchased under a contract between Westinghouse Electric Corporation and Rolls Royce. Britain's second nuclear submarine, the SSN.02, will have a British reactor similar to *Dreadnought*'s but with some British features incorporated. The remainder of the machinery will be British.

Work on this prototype reactor is being done at Dounreay where a full scale training model is being built with a half hull which will contain the reactor. It is expected to go critical in mid-1962.

The main contractors for the submarines are Vickers-Armstrongs Ltd and Rolls Royce and Associates. No further contracts are expected to be placed within the next 12 months.

- **Euratom** Agreement to undertake a study with the French CEA on a graphite-moderated reactor for power and ship propulsion has been given by the Scientific and Technical Committee.

- **France** An aerial survey of Normandy to discover uranium ore deposits is being undertaken.

- **France** Another minor fault developed in the G2 reactor at Marcoule when a break occurred in the CO_2 gas line. The fault took two days to repair.

- **Sweden** The FR-O fast reactor is now in the preliminary design stage and is scheduled to be in operation by 1962.

- **Euratom** The Scientific and Technical Committee has approved a decision to set up a radioisotope information centre.

- **France** The decision to have a concrete pressure vessel for EDF-2 is now being reconsidered. Studies are under way to consider the relative merits of concrete and steel pressure vessels.

ICSE experiment abandoned

London Cost factors and limited scientific resources have led to the abandonment of the thermonuclear experiment, ICSE (Intermediate Current Stability Experiment) by the AEA.

Sir William Penny, Member of Scientific Research, said original costs had been estimated at about £M1·5. 'Now we find that it will certainly be twice that and possibly rather more', he added. However, even if the money were available, he would not proceed with ICSE because it would occupy too much scientific time.

Despite this setback, the UK fusion programme will continue and will be broadened with a number of smaller research experiments, improved methods of diagnostic measurements and the development of advanced techniques.

Money spent so far on ICSE amounted to about £500,000 but the apparatus ordered could be used for other basic work, Sir William said. 'We will almost certainly one day want to construct a large apparatus but when that is done is largely a matter of scientific judgment and scientific timing', he stated.

Gas centrifuge storm

London After the sudden flare-up of publicity over the West German gas centrifuge method for the enrichment of the uranium isotope, the German Federal Government has applied to the patents office to have the process listed as a state secret.

This may now appear to be too late as the process is not new (see *Points from Papers*, this issue and 1958 Geneva Conference paper 'Enrichment of the uranium isotope by the Gas Centrifuge method' by W. E. Groth, K. Beyerle, E. Nahn and K. H. Welge). What is new is the sudden realization that potentially, the method can produce enriched uranium at 10% of the power cost of the gas diffusion method. Investment costs are still reported to be high. However, it should be remembered that the system has been investigated by the US, Britain and France—all of whom have gas diffusion plants.

The gas centrifuge method subjects uranium to centrifugal force under high temperature, separating the U-235 from the U-238. No large scale pilot plant has yet been built and it will be several years before the method is proved to be economically superior to the gas diffusion plant.

The West German firm Degussa, which has played a large part in the development of the gas centrifuge method, has denied reports that an American firm in Santa Fe had bought one of its machines. Other firms carrying out work on the process are reported to be AEG and H. Martin of Kiel.

OVERSEAS

India issues tenders for first station

Bombay India has issued its expected invitation for global tenders for its first nuclear power station (see *Worldview*, October, p. 72), to be built at Tarapur, about 62 miles north of Bombay. Tenderers have been given about 7½ months to prepare and submit their tenders.

According to an official announcement from the Department of Atomic Energy, the power station will produce about 300 MW and will consist of two reactors of equal capacity. Special emphasis has been laid down for keeping the foreign exchange complement to a minimum. In addition, tenderers are to employ, to the greatest extent possible, Indian materials, locally fabricated and Indian personnel.

The station is scheduled to be completed in 1965 and, when finished, will meet most of the power needs of the two states of Maharashtra and Gujerat.

The GEC have already indicated their willingness to tender (see *Worldview*, May, p. 85) but the position of the other groups is not yet clear as full details, *Nuclear Power* understands, had not reached this country at the time inquiries were made.

Canadian Nuclear Association

Toronto The proposed Canadian Nuclear Association has now come into being (see *Worldview*, May, p.92). It has four main objectives: promoting an environment favouring healthy growth in the uses of nuclear energy; encourage co-operation between industry, Government bodies and other agencies; to provide a forum for discussion and to stimulate co-operation among other associations that have similar objectives and purposes. The president is Mr I. McRae of Canadian General Electric.

AEC stops work on test reactor

Washington Design work on the proposed Idaho Falls water-cooled Nuclear Test Plant (NTP) has been stopped by the AEC. The reactor was to be built for the Army but when they withdrew their share of funds, the AEC decided to stop work and use the money it had budgeted for this project, for other work.

The NTP would have used a water-cooled system having maximum flexibility and extensive instrumentation to facilitate full-scale testing of prototype cores and control systems of varied designs. It was a test project for developing reactors which the Army could have used.

South African research centre

Cape Town Work is to begin soon on a £500,000 research centre for Cape Town and Stellenbosch Universities. A 300 acre site at Faure near Cape Town is now being surveyed. Most of the running expenses will be met by the South African Atomic Energy Board.

• **United States** A small nuclear power plant to convert heat directly into electricity for use in satellites and manned space vehicles is being developed by the US General Electric Company.

• **United States** A cheque for nearly £11,700 was presented to Austria by the US in order to develop training and research facilities.

• **United States** Costs of over £M19 were incurred during the three months ended June 30, 1960, on civilian nuclear reactor projects under active design or construction for installation in the US.

• **Australia** Advanced Technology Laboratories of California has received an export licence for the 10 kW water-moderated UTR-10 research reactor it is to provide for the Australian AEC.

• **Canada** Sirmac Mines have discovered what is described as the largest and best grade lithium deposits known in Canada.

• **Japan** The heavy water research reactor at Tokai-Mura, supplied by American Machine and Foundry Company, has gone critical.

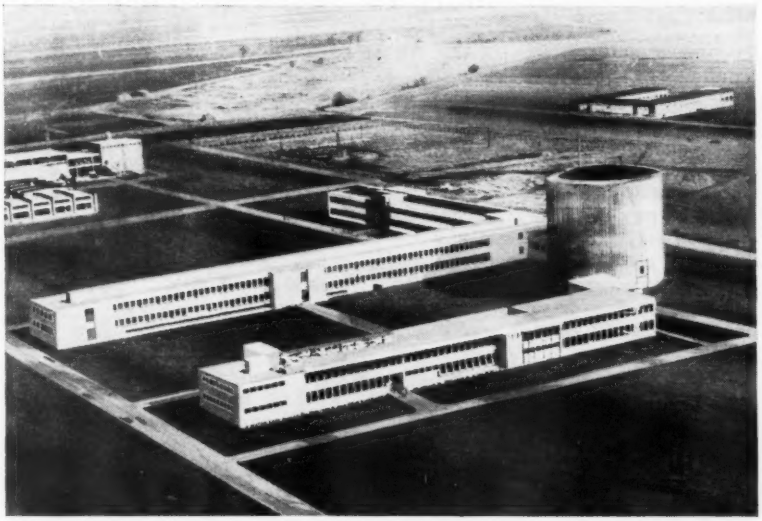
• **Soviet Union** Two mass spectrometers for use in nuclear and electronic engineering research have been ordered from AEI. The order was worth £50,000.

Reactor design study for Spanish agency

Washington A multi-purpose nuclear power plant design study for the Spanish Junta de Energie Nuclear has been completed by Atomics International. It includes facilities for nuclear research in addition to a 30 MW generating capacity. An earlier conceptual design study was conducted by the same firm for the Junta. The new study increases the power from 20 MW. The reactor itself will be cooled by an organic fluid and deuterium oxide will be the moderator.

GE test reactor success

Washington Successful operation of the Nuclear Test Reactor (NTR) by the General Electric Company in the year ending August 31 was reported to the USAEC. During this period, the NTR was critical for 586 hours with 88 hours spent approaching criticality.



AUSTRIAN REACTOR Europe's most advanced nuclear research reactor and Austria's first, has started operating at Seibersdorf near Vienna. Designed and built by American Machine & Foundry Company, the reactor is the heart of a new nuclear research centre (above) built for the Austrian Study Group for Atomic Energy, a joint government-industry organization consisting of more than 60 Austrian companies

WORLDVIEW

Decisive year ahead for IAEA

Vienna The coming year will be the start of a period of decision for the International Atomic Energy Agency, the Director General, Sterling Cole, said at the Fourth IAEA General Conference.

The IAEA was in the midst of a period of consolidation and had tried to prepare itself for the longer-term and greater tasks for which it was created and whose challenge it would soon, he hoped, be called up to meet.

He regretted that nothing had come of his recommendations to: register with the Agency all international shipments of uranium; place under Agency administration international traffic in uranium; apply Agency safeguards to the peacetime facilities in atomic countries; grant a discount or preference to the Agency in the price of U-235 and co-ordinate research in nuclear fusion.

The Director General also expressed concern about the lack of funds to support IAEA programmes and its costly administrative machinery. He added: 'Let me express the hope that the future will give us more fellowships, more research, more equipment, more technical experts, that the emphasis will be increasingly placed on action programmes and that the extent and importance of our future activities will justify the heavy supervisory machinery that the Statute and practice now impose upon us. . . . Our financial predicament could be readily and adequately solved if each of the atomic countries were to turn over to the Agency some of their U-235 material now in weapons stockpile. And . . . I seriously commend this course of action . . .' he concluded.

The Conference, in its business, approved a draft relationship agreement between the IAEA and the European Nuclear Energy Agency—an agreement which is an initial step towards close working relations and co-ordination of effort between the two bodies.

Other Conference decisions were as follows:

A request that the IAEA study and report on the question of establishing an international centre for theoretical physics; approval of the IAEA's provisional regulations for the transport of radioactive materials and a recommendation that member states use them as a basis for relevant national regulations; a request that the Agency arrange for international exchange of abstracts and documents relating to peaceful uses of atomic energy; that the Agency should explore co-operation in the field of radiation and neutron standards with other international bodies; make nuclear power surveys in member states at their request and continue to collect and study data on nuclear power costs.

Power problems of new states

Tel Aviv One of the features of the recent International Conference on Science in the Advancement of New States was the world-wide interest it aroused. Held at the Weizmann Institute of Science, Rehovoth, it attracted the attention of most of the leading scientists of the world and, on the nuclear side, contributions came from such prominent personalities as Alvin M. Weinburg, J. A. Jukes of the UKAEA, Dr Jules M. Gueron of Euratom and Marshall Brucer, chairman of the Medical Division, Oak Ridge Institute of Nuclear Studies.

The Governor of the Bank of Israel, David Horowitz, spotlighted the problem in his paper 'Politics and Economics and New States', when he said what was 'urgently needed is promotion of an international economic equilibrium by directing the flow of capital equipment to areas where it is most needed and, simultaneously, attainment of a high level of employment in the mature economies engaged in producing such equipment'.

While pointing out that the immediate prospects for nuclear power in New States were limited to a few special cases, Mr J. A. Jukes said it would become of increasing importance as the New States approached maturity. In his paper 'The Economic Prospects of Nuclear Power in New States', he said in 10 or 20 years time, consumption by these states would have increased five times or more and concentration of demand will have been brought into being which would enable full use to be taken of intensive forms of energy production. Nuclear power might then be vital.

He discussed the stage in development of New States at which they would be able to make use of nuclear energy with advantage. This would probably be after ten years had elapsed, if not longer. The advantage for these states was that they could afford to wait and had no need to rush into a new technology which would consume their most valuable resources—scarce scientific manpower and scarce capital. Nuclear power would become progressively more competitive and would reduce the pressure on world energy resources and help to prevent any violent rise in their energy costs.

Dr Gueron, General Director of Research for the European Atomic Energy Community, outlined the problems involved in developing nuclear power. These problems—technical, administrative and technological—were part of the price paid for the promise of the large energy multiplying factors of which they were trying to take advantage.

Dr Weinburg took the approach that probably the best course for a new country was to maintain a small cadre of domestic experts who would buy reactors with discrimination and operate them with intelligence when reliable reactors became available. 'Research carried on by such a cadre should be aimed at specific questions imposed by the particular geographic conditions of a country—how much uranium and thorium and at what costs is available within the country; is there enough low cost-material for initial inventory; are there clear solutions to the problem of waste disposal given the country's geographic and geologic environment?'

'I do not advocate ignoring nuclear energy entirely', he stated. 'I do urge going at it sparingly until it becomes clear that its exploitation will add to the economic strength of a country rather than drain resources of men, materials and foreign exchange from more urgently needed enterprises'.

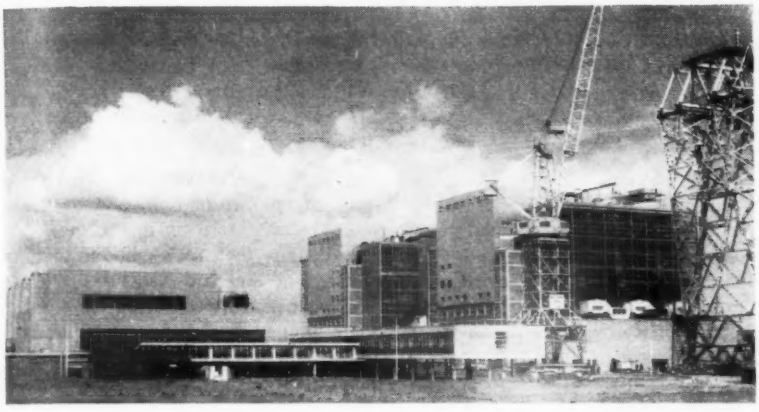
Dr Weinburg pointed out that, in principle, a country well-endowed with uranium and thorium could become self-sufficient in energy. If breeder reactors could be reduced to reliable practice, the recurring requirements of uranium and thorium become so low as to make every country, large or small, potentially autarkic (self-sufficient) with respect to central station energy, provided material for initial inventory was available at reasonable cost.

Other questions, of course, had to be answered. Was the mining of rocks for residual uranium really practical? Was the matter of conversion of nuclear energy into other more convenient forms of energy practicable? What kind of world would there be if energy autarky was achieved generally?

The outlines of such an energy autarky were clear and technically sound. It could be possible within 50 years time.

The UK's Nuclear Power Stations

Latest pictures of the five stations now under construction (see articles on pp. 74–88)

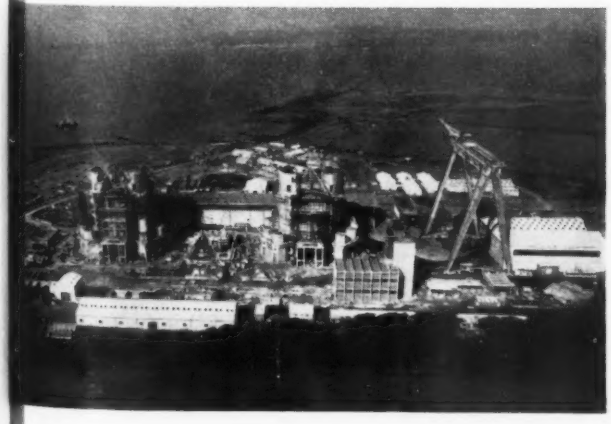


The 275 MW station at Berkeley showing No 1 and No 2 reactors (top). Being built by The Nuclear Power Group, it is scheduled to go critical next year

A general view (left) of TNPG's 300 MW Bradwell power station, looking northwards. This station is also to go critical next year

The English Electric-Babcock & Wilcox-Taylor Woodrow station at Hinkley Point (right), the UK's first 500 MW station

An aerial view of the 300 MW Hunterston station (below) being built for the South of Scotland Electricity Board by the GEC-Simon Carves Atomic Energy Group. The first steam-raising unit of reactor 'A' can be seen on its plinth



A general view (below) looking south, of the site of the 500 MW Trawsfynydd station being built by Atomic Power Constructions Ltd

Modifications due to new graphite data and increased standards of safety have been incorporated

BERKELEY—Construction and design changes

by J. R. M. SOUTHWOOD, B.Sc., A.M.I.E.E., Deputy Chief Engineer, The Nuclear Power Group, E. L. HASTE, B.Sc., A.M.I.C.E., Chief Resident Engineer, AEI-John Thompson Nuclear Energy Co. Ltd, W. L. PARTRIDGE, A.M.Inst.Fuel, Projects Manager, R. DERRICK, M.I.Mech.E., Inspection Engineer, R. W. DAY, O.B.E., B.Sc., M.I.Mech.E., Chief Inspector, The Nuclear Power Group

WHEN THE FIRST DESIGNS for nuclear power stations were prepared by the Nuclear Consortia for submission to the CEGB in October 1956, the first Calder reactor had not yet been commissioned and the only available experience was on design and construction. In addition, the research and development programme in support of the Calder design was of a fairly limited nature and a much more comprehensive programme was getting under way to investigate the many problems which had been revealed during the design stages. It was to be expected, therefore, that as operational experience was obtained on the Calder reactors, new data would be accumulated which would inevitably affect the design conception of the first civil reactors.

In the event, there have been several design changes incorporated as a result of the Calder operational experience, which have inevitably had some effect on the programme, delaying completion by something like nine months.

The most significant changes have been brought about by the research and development programme and two of these will illustrate the effect on design. The properties of graphite after irradiation were not clearly defined at the time of tendering and an intensive programme of investigation was undertaken by the AEA to obtain more information on stored energy and graphite growth at the higher fuel ratings and gas temperatures used in the CEGB reactors. The problem of stored energy build-up appeared to be increasing as more data became available and it was decided that measures to increase the graphite temperature would be necessary to limit the stored energy build-up to an acceptable level. To this end, sleeving of the fuel channels was investigated. The non-circular fuel channel shape used in the Berkeley reactor prevented the use of a graphite sleeve and, consequently, a magnox sleeve was introduced. The state of the construction programme at the time this decision was made, called for a very intensive programme of investigation in order that sleeves of the required quality could be obtained; success was achieved only just in time to prevent a serious delay in graphite laying. Subsequent data obtained from the development programme now suggested that the precaution of introducing these sleeves into the channel was not as necessary as had appeared at the time the decision had to be taken. However, it is impossible to revert to an unsleeved reactor at this stage since the entire core is now completed and the sleeves therefore remain. In parallel with the stored energy information, data was being obtained on graphite growth. Here again, as new data appeared, it became obvious that some modification to the brick and tile design in the core was necessary and extensive remachining has been carried out on the graphite bricks to accommodate the new growth figures obtained.

The above illustrates the effect of new data on reactor components. A similar situation has arisen on the reactor control system. Xenon, one of the neutron absorbing fission products produced in the fuel, has a strong modifying effect on the control characteristic of the reactor. A theoretical study indicated that in a very large core, as at Berkeley, some instability and power surging between sectors of the core might result from the xenon build-up. An extensive study of the phenomenon was made on the largest computer available and it was finally concluded that such fluctuations should be damped out since they could, if allowed to proceed, shut the reactor down due to high temperature or high flux in one part of the core. The original reactor control system depended on a large number of absorber rods being moved in unison into the core. This new requirement called for segregation of the movement of these rods and the installation of individual control loops in sectors of the core so that any local fluctuation would be detected and corrected by control rod movement without causing any general power disturbances. Inevitably, the addition of these individual control loops required a careful study of the effect on the whole control system to ensure stability and to minimize temperature fluctuations which might have an adverse effect on the fuel element.

Increased standards of safety have also brought about changes during the construction period, the first of these being the new international radiological standard where the permitted radiation level in buildings around the reactor was reduced. This standard only became effective after most of the shielding had been constructed and, as a result, a good deal of modification to work on site had to be made. Fortunately, the increased thickness of walls called for, did not seriously affect the plant layout.

SITE STAFF AND ORGANIZATION

At Berkeley, the civil engineers and clerks of works were on site first, followed shortly by a nucleus of mech-

anical engineers. The pressure vessel was built on site and the boilers fabricated in a site workshop from pieces of a transportable size. Consequently, after two years mechanical engineers and inspectors were equal in number to the civils, and soon exceeded them. Though an electrical engineer had been required almost from the start to look after power supplies for temporary works, it was not until the middle of the second year that electrical engineers were required in numbers for the permanent works. Their strength, however, never reached that of either civils or mechanicals. Graduate apprentices from the parent companies in the AEI Group were also given periods of training on site of three to six months and proved very useful. The mechanical staff, in particular, was larger than would have been expected for a conventional station due to the high standard of supervision and the comprehensive nature of the work subject to a high standard of inspection (pressure vessels and heat exchangers).

The size of the Resident Engineer's staff was also affected by the decision, made at an early stage, that the Group, as the body responsible to the CEGB, should continuously supervise the work of the specialist contractors, thereby giving centralized direction to the whole project.

Site services were, as far as possible, supplied by member companies and sub-contractors and not by the Group. These included water supply, temporary electrical supply, main cranage, personnel transport, labour camp, etc. so that the Resident Engineer should not have to employ a large directly-employed labour force. Even so, it was found necessary to employ a certain force of cleaners, chainmen and storemen. Drivers for permanent lifts and cranes were engaged when these were installed and used for construction work.

In addition to the above, there was a small clerical staff, a security force and a small drawing office. The Group also employed a Labour Relations Officer and a resident PRO. The Group's civil consulting engineers and their quantity surveyors had resident staffs on site.

Specific nuclear training at Calder Hall was given to the senior electrical and mechanical engineers before the contract was placed and short periods at Chapelcross were arranged for those in charge of the reactor core and instrumentation.

The total area of the site within the CEGB boundaries was 93 acres. Some of this was inconveniently situated, some used for temporary topsoil dumps and some used for the switchgear compound. Of the rest, 25 acres were occupied by permanent buildings and 37 acres for contractors' storage and workshop areas. The greater part was taken up by civil contractors for reinforcement storage and bending, precast concrete work, carpenters' shops, plant maintenance and general storage (see Fig. 1).

The next largest contractors' areas were those for boiler fabrication and work associated with the reactor. Storage space for graphite components was arranged in one of the permanent buildings, which was constructed early for this purpose. The requirements for storage space was kept within reasonable limits, as far as possible, by so arranging deliveries that storage was not required. When the last boiler was out of the fabrication shop, this building was used as covered storage.

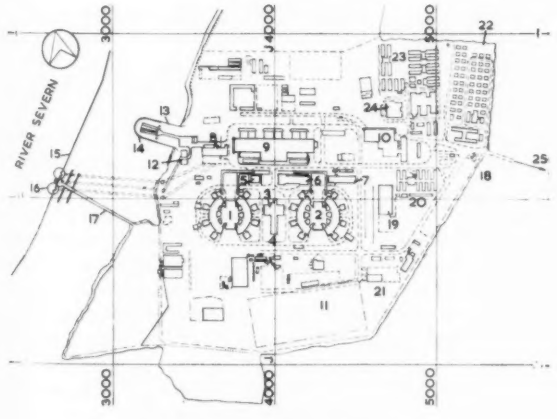
Owing to the more stringent requirements of nuclear work, a site concrete laboratory was set up which was equipped to carry out density tests and trials of unusual mixes, and to exercise strict control over all concrete work. Slump tests, for instance, were not considered satisfactory for the control of water content and water/cement ratios and wet and dry densities were carefully watched.

To meet Lloyd's requirements on inspection, every welder who carried out work on the pressure circuit was subjected to a series of tests to simulate the job on which he was to be engaged. The test specimens were welded and examined to the British Standard. A Welding Test School was established on site to deal with the large volume of tests to be done, and here, apart from the selection of tradesmen by means of the test, such training and welding development work as proved necessary was carried out.

Once the reactor vessel shell was completed, tested and cleaned down inside, clean conditions were established. This involved the setting up of temporary facilities, taking up four floors in the reactor annexe. These facilities comprised change rooms, showers and, to avoid unnecessary changes at meal breaks, a canteen was also established inside the clean conditions area. Three of the floors were taken over for the storage and handling of materials into the reactor.

Similar arrangements were necessary for tubing the sixteen boilers, each of which was at some time capped with a clean conditions house in which boiler internals, delivered in sealed polythene, were unpacked, inspected and passed into the boilers. Complete changes of clothing were not required for the boilers—gloves, caps, boilersuits and special shoes were considered adequate—so washing facilities were not provided there.

The short programme did not in itself pose any specifically new problems, but it did lay more emphasis on efficient organization and timing of deliveries, and, of course, called for more man power and plant than for a conventional station.



Site plan of Berkeley (Fig. 1)

1 Reactor No 1; 2 Reactor No 2; 3 Cooling ponds; 4 Decontamination; 5 CO_2 store; 6 Charge room unit; 7 Fuel element store; 8 Pumphouse; 9 Turbine hall; 10 Admin block; 11 132 kV CEGB switchgear compound; 12 Sewage disposal; 13 Cooling water outfall; 14 Coffer dam; 15 Baffle wall; 16 Cooling water intake; 17 Bailey bridge; 18 Site fence; 19 Boiler shop; 20 Admin block; 21 Plant shop; 22 Bungalow site; 23 Labour camp; 24 Cinema; 25 Road to Berkeley.

In drawing up the programme, it became evident that the critical item was the reactors themselves. It was decided to construct the pressure vessels *in situ* from small plates, a method which allowed small cranes to be used. The largest temporary cranes on site were four 15-ton monotowers in fixed positions. This arrangement gave flexibility and allowed civil and mechanical works to be, to some extent, independent of each other.

Once the programme for the reactors was established, it was possible to arrange the civil works, boilers and pressure circuits, conventional plant and ancillary works to fit in with it and this, therefore, became the key programme. There was one exception. The pressure vessel having to be constructed *in situ* from small plates, it was found that the foundations for the first reactor could not be made ready in time to construct the whole of this vessel *in situ*. The bottom dome was, therefore, constructed on site adjacent to the reactor building and moved into its final position on bogies when the foundations had reached a suitable height. It was not necessary to do this in Reactor 2 which was built wholly *in situ*.

The key dates established were:

1. The moving in of the P.V. bottom dome
2. Stress relief and pressure test
3. Establishment of clean conditions
4. Closure of the vessel and circuit testing
5. Fuel loading.

Other subsidiary key dates followed from this. For example, boilers, blowers and ducting had to be completed by circuit testing date and the programme to achieve this called for power and cooling water supplies in time for testing the first blower. At the same time, deliveries to site from the manufacturers also had to be programmed. After establishment of the master programme, the organization to maintain it was partly at headquarters and partly on site. Progressing through manufacturers to delivery on site was carried out by headquarters staff and progressing on site by the site staff.

PROGRAMME CONTROL

The time period allowed from the date of access to site to the completion of construction and commencing of fuel loading was 41 months for Reactor 1 and 48 months for Reactor 2 to comply with the national programme of the CEGB. However, advantage was taken of the fact that the site was accessible two months earlier than the programme date, so that an early start was made with the initial phases of the work.

The novel requirements of the first nuclear stations dictated that planning should allow a sufficient flexibility to accommodate significant changes. Such changes resulted from the development of detailed designs and of procedures in manufacturing, construction and inspection methods to meet the needs of compatibility, extreme cleanliness and the unusual standards specified for construction. At the same time, efficient co-ordination of the efforts of a large number of specialist contractors depended largely on the extent to which it was possible to accommodate these changes within the main programme. Planning covered each main plant item, design, manufacture and construction periods and incorporated, where applicable, the necessary development work, prototype tests, proving and performance tests at works or site.

From the programme control, a normal procedure was adopted of examining design progress by monthly meetings between the CEGB, the Atomic Energy Authority and the Contractor. At monthly site meetings, the progress of manufacture and construction was similarly reviewed. Within the framework of the main programme, the day to day construction works was programmed in great detail on site, according to the existing situation and the monthly forecasts of material deliveries. The aim of the routine progress meetings was to foresee possible causes of delay, so that, where practicable, action could be taken before site work was affected. An example is the series of detailed procedures which were agreed in advance to cover many novel features of construction work on site, such as the stress relief of reactor vessels or boiler shells.

The commissioning phase has similarly been planned in great detail and working procedures have been agreed in advance by all bodies concerned.

The regular comparison between programme and progress sought to provide the earliest warning when the inevitable unforeseen delays occurred. Since the construction programme was, as far as possible, based on single shift working over a six-day week, it was frequently possible, by employing an additional shift or by extra weekend work to make good delays.

INSPECTION PROCEDURES

For the purpose of inspection, conventional plant at both Bradwell and Berkeley Nuclear Power Stations has been treated in precisely the same way as for a conventional station.

The plate for the reactor pressure vessels was ultrasonically examined at the steelworks and the usual mechanical tests witnessed, impact values being of particular importance in view of the effects of irradiation and the extent of site welding to be carried out. Weld procedure tests were carried out on all joint designs used in the vessel. Examination of weld preparation included edge magnetic crack detection and an ultrasonic survey about 2 in. from the plate edge. All site examinations were made as for Conventional Class I work, great emphasis being placed on accuracy of assembly.

The use of graphite as a moderator has called for the greatest possible degree of homogeneity and also exceptional dimensional accuracy in manufacture. Both these aspects are the subject of close inspection to very tight specifications.

A further feature peculiar to nuclear power generation and plant operation is the absolute necessity of maintaining clean conditions in the nuclear circuit. This condition is met at the very outset of manufacture; thus at manufacturer's works, as well as at site, all materials in contact with the radioactive gases must be manufactured clean, or assembled and then cleaned to a specification which is far beyond the usual commercial standards. The setting up and maintenance of clean rooms and areas and the continuous inspection during manufacture is new both to manufacturers and inspectors, but is rapidly being accepted as a normal requirement for nuclear work. The elimination of all incompatible materials and substances from contact with the radioactive gases is also vital and has to be be watched continuously by both designers and inspectors.

This station is now in the commissioning stage and the fuel elements for it are in production

BRADWELL—Construction and design changes

by R. D. VAUGHAN, B.Mech.E., A.M.I.Mech.E., Chief Engineer, The Nuclear Power Group, A. YOUNG, M.I.Mech.E., Chief Resident Engineer, and E. ANDERSON, B.Sc., M.I.Mech.E., A.M.I.E.E., Chief Contracts Engineer, The Nuclear Power Plant Co. Ltd

THE BASIC PRINCIPLE in the conception of Bradwell was that the design and operation of the reactor unit should be as simple and straightforward as possible. This was manifest, for example, in the adoption of a uniform channel diameter throughout the reactor core, the absence of moving parts on the fuel element, electric motor drive for all gas circulators from a single speed control and in the single multipurpose fuel charging machine.

It was also decided very early in the design to have inside the reactor vessel, the absolute minimum of equipment which was not capable of removal for inspection or replacement. On this account, there was no internal skin within the vessel which would have been required with internal shell cooling or insulation. The pipework for the fission product detection system was arranged to enter the reactor shell through standpipes in bundles which could be withdrawn at any time. And no part of the charging equipment was required to remain inside the vessel when not in use.

To provide for uninterrupted base load operation over a period of months, on-load fuel changing was adopted and the access for refuelling was provided through standpipes entirely separate from the control rods so that the control mechanism need not be disturbed during the charging operation.

Finally, it was considered important that the layout should provide for the maximum intrinsic safety so that the plant as a whole would not depend any more than was absolutely necessary on auxiliary tripping mechanisms and control circuits for ultimate safety under major fault conditions. It was, therefore, considered desirable to arrange for the level of boilers and reactors to be such that the pressure differentials in the gas circuit provided for the maximum amount of natural circulation.

These principles were laid down before any experience had been gained in the operation of the first Calder reactors. Such experience has highlighted certain aspects of the Bradwell design and has resulted in some changes but not in the basic thermodynamic performance or plant layout. It is also well known that the incident with No. 1 reactor at Windscale caused a certain amount of rethinking in regard to the graphite structure which has had its effect on Bradwell.

At one stage it was considered that the gas inlet temperature, and hence the graphite temperature, at Bradwell was not high enough to prevent a critical accumulation of Wigner energy in the life of the reactor. Some considerable effort, therefore, was spent on the design of graphite sleeves which would insulate the graphite from the fuel channels in order to raise the graphite temperature. Work was done on the redesign of fuel handling equipment so that it could also withdraw sleeves of graphite from the channels. A large amount of experimental work was undertaken on the properties and behaviour of the sleeves themselves. However, as more data on Wigner energy storage became available, the earlier predictions were found to be unduly pessimistic, and it was felt that the technical problems associated with sleeves would not be justified by the long term gains they would bring about. It has now been decided to omit sleeves and the design, as far as the fuel channels are concerned, remains as originally tendered.

Along with the extensive work on Wigner energy storage, much new information on dimensional changes in graphite was obtained. This revealed at quite a late stage that nuclear graphite is likely to shrink in certain directions under irradiation. This would have meant the moderator bricks becoming loose in the core with a consequent increase in CO_2 leakage between channels and possible difficulties with insertion of fuel and control rods due to change in shape of the channels. The original design of core relied entirely upon the graphite tiles to maintain the geometry; but with the possibility that these tiles would change in dimensions, it was necessary to introduce another material which did not suffer such changes and eventually zirconium pins were chosen as spacers to keep the columns of graphite bricks at a constant distance one from another. The introduction of zirconium pins had no material effect on the construction programme for the graphite cores.

Just as the core began as an extremely simple conception and has become more complicated in order to accommodate new data on the properties of graphite, so also the fuel element is no longer quite as simple and straightforward as was originally intended. The fuel bar was originally contained in an extruded spirally finned can with four longitudinal splitters which had the combined function of preventing bowing in the channel and dividing the flow to promote heat transfer. The end fittings were simple cup and cone arrangements which did not require to be orientated in the channel and could be withdrawn with a simple grab into the charge machine.

When the first complete fuel elements were manufac-

tured and tested under conditions of temperature and gas flow closely approaching those in the reactor, it was found that the aerodynamic forces were unstable and this resulted in severe rattling which damaged the magnesium fitments on the can. The exact mechanism of rattling is very difficult to analyse and information on the subject is still largely empirical. However it has been found that the problem can be overcome by applying a constant lateral force to the fuel element and this will be done on the first charge for Bradwell with a spring-loaded slipper built onto the top end fitting. Apart from this modification, it has been found necessary to stiffen the longitudinal splitters with a number of braces which has had some effect on pressure drop in the channel but no effect on the heat transfer performance.

In the securing of maximum intrinsic safety in the plant, there has been no change in the basic mechanical layout of boilers, blowers and gas circuits. Flywheels have been added to the blower drives to provide additional inertia and thereby ensure a longer run down in the event of a failure of supply.

In the control system it was found on closer analysis that flux instability could occur between one part of the core and another owing to the much larger size of core than was used for the Calder reactors. To prevent surging as a result of this instability it has been necessary to control separate parts of the core independently by groups of automatically controlled rods, now known as the sector control system. This has inevitably resulted in some additional equipment in the control rod supplies.

Throughout the construction of Bradwell constant attention has been devoted to ways of ensuring that incidents which would be disastrous to either the neighbourhood or to the reactor itself cannot occur. The normal control and safety rods are all tripped from signals outside the reactor vessel itself and an accident might be postulated because insertion of control rods was not initiated or the signal came to late. The latest philosophy therefore is to arrange that neutron absorbing material will fall into the core immediately there is some major change in the operating conditions such as gas pressure or temperature.

The mechanisms which bring this about are known as secondary shutdown units and they operate only if the normal safety circuits are ineffective or too slow. The simplest of such devices is one which releases the control rods from their suspensions by direct mechanical action the moment something untoward happens in the core. At the same time, of course, it is necessary to redesign certain items of the core supporting structures to ensure that the control rod channels do not change shape in the event of a major accident to the reactor vessel.

About six months after construction had begun on Bradwell, a reduction in the radiation levels considered acceptable to the human body was introduced by the Medical Research Council. This meant that many parts of the plant, which had been considered safe for whole time access, became safe only for part time access. In particular, radiation from the four boiler houses in Bradwell became quite a hazard which necessitated thickening the shielding over the blower houses and along the side of the turbine house. The administration block was originally located halfway along the turbine house directly facing two of the boiler houses and a decision was made fairly early that the administration block be moved bodily away from the reactor buildings. The changes introduced at this stage made it possible to operate the station without any additional staff on account of increased irradiation levels in working areas, but they resulted in increased costs on the civil work.

Apart from the specific changes mentioned above it is fair to state that all the principles laid down for the original design have been adhered to. It is reassuring to note that so many of the features of Bradwell have been adopted in later designs now under construction, although of course this makes it even more important that these principles should be sound.

SITE STAFF AND ORGANIZATION

The construction of a nuclear power station differs from a conventional power station only in so far as the reactor itself and its associated equipment are concerned. In the ordinary way, a building is constructed and equipment installed afterwards. The construction of a reactor varies because of the fact that certain vital equipment is built into the concrete structure as it progresses and particular items of engineering equipment require to be set up to very close tolerances before being built into the structure.

At Bradwell, the Chief Resident Engineer is responsible for the overall administration of site work; he is assisted by a Deputy Chief Resident Engineer. Supporting the Chief Resident Engineer are:

(1) A Group Engineer for reactors and associated equipment.

(2) A Group Engineer for power plant (turbo-alternators, cooling water system and associated services).

(3) A Group Electrical Engineer responsible for the whole of the electrical installation—lighting, power, distribution, instrumentation, etc. This engineer provides service to the Reactor Group Engineer and the Power Group Engineer.

(4) A Group Civil Engineer responsible for all civil engineering and building work on site. His work is organised to meet the requirements of the Group Engineers on reactors and power plant.

Each Group Engineer leads a small team of specialist engineers who are responsible to him for the direction of particular items of work which fall within his sphere of influence.

The total number of staff employed by the NPPC at Bradwell did not exceed 80 when the peak labour force was 1850. This number included office staff, stores, security, first-aid, fire and ambulance services, etc.

For engineering supervisory and inspection staff, it is desirable, but not always possible, to have 60% qualified engineers and 40% 'clerk-of-works' type, the latter usually recruited from the foremen level of craftsmen. At Bradwell, this ratio has, in most respects, been achieved. The senior engineers have all had previous experience on large construction and engineering projects, some in the nuclear field. The Chief Resident Engineer was associated, in a senior capacity, with the building of Windscale and Calder Hall.

Site accommodation is provided for single supervisory staff in a self-contained building called The Ranch. Their married equivalents live in Company houses in nearby villages or towns. For the general labour force, there is a hutted camp for 900 people and this was fully occupied

during the time of peak employment. Coach facilities are provided for workpeople living in surrounding districts.

At Bradwell, it was decided that the two reactor vessels should be fabricated on site but outside the civil engineering construction area. In order to facilitate this technique, a Goliath crane, which spanned the full width of the reactors, was provided. It was designed to give service from the constructional area of the reactor vessel at the south end of the site to a point north of the two reactor buildings. This facility allowed the civil engineering work on the reactor to proceed whilst the fabrication of the vessel was in progress, the Goliath crane carrying down the completed sections to the vessel and placing them within the concrete vault; the maximum weights lifted and carried were each in the region of 200 tons. The heat exchangers were towed down by sea from the North-east coast as complete shells to a prepared slipway on the banks of the Blackwater estuary, and transported by road to site, where they were lifted by the Goliath and placed on their foundations.

One of the problems at Bradwell was that the ground level had to be built up an additional 12 ft. This fill was provided from the excavations of the reactors and the turbine hall. Permanent roads, therefore, could not be laid until the fill was provided and ultimately consolidated. This meant also that drains could not be placed and, in consequence, any heavy rainfall created extremely difficult conditions, which will be appreciated when it is remembered that the fill was London clay.

General services in the form of mobile cranes, lorries, compressors, tractors, etc. are provided by one of the main contractors. These services are put at the disposal of all contractors on site at the normal hire rate. This contract also carries a small group of craftsmen who are mainly used for maintenance work, but are also called upon to install plant where the contract has been let on a 'supply and deliver' basis.

An important feature in the building of a nuclear power station is the establishment, at an early stage, of 'clean conditions'. These conditions are necessary for the tubing of boilers, for the installation of control equipment, the construction of the charge/discharge machine, etc. The interior of the reactor pressure vessels must be cleaned to a very high standard. Working within the vessels, as for laying of graphite, calls for a special arrangement of change rooms and clothing.

Another feature at Bradwell which has proved advantageous is the central store yard equipped with cranage. When it is considered that there are eight main contractors on Bradwell site, plus sub-contractors, the alternative to a central store yard would be numerous separate store yards, each requiring cranage facilities.

CONTRACT ORGANIZATION

The organization for handling the Bradwell contract was built up on the basis of Engineer and Drawing Office Staff seconded from the constituent Member Companies of The Nuclear Power Plant Company Limited, and supplemented by local engagement. At the time the contract was awarded, the organization was about a hundred strong, consisting of Mechanical, Electrical and Civil Design Divisions, with a Co-ordinating Division which, in the tender stage, had handled overall layouts and conventional work.

With the prospect of overseas tenders and more advanced designs to prepare, it was decided to relieve the Design Divisions of the day-to-day work of the contract and a Contract Division, supplemented by Progress, Planning and Inspection Sections, was formed for this purpose. The function of the Design Divisions was then to complete the development of the designs already carried far in the tender stage and, having seen the work through experimental or prototype stages, to hand over to the Contract Division to follow through the engineering detail, to complete specifications and to obtain the clients' final approval. This form of organization successfully fulfilled the requirements of the original conception.

Such difficulties as were experienced were mainly due to design modifications resulting from a rapidly changing technology; this made it difficult to adhere to the design programmes and led to continual revision of staff requirements. The necessity to build up and train staff and to devise the administrative procedures required in a new organization added considerably to an already formidable task.

Monthly design progress meetings and site progress meetings were held between the CEGB, the Atomic Energy Authority, and the Contractor, in addition to the many meetings on particular facets of design, administration or commerce. Member Companies' representatives were called to monthly design progress meetings.

The close co-operation of each of the Member Companies was required in the preparation of the main construction programme which covered some fifty headings only. This was supplemented by a number of detailed construction programmes and manufacturing programmes for each main group of plant items. These manufacturing programmes provided a foundation for the work of the Progress Section, for although each Member Company progressed the work of their sub-contractors, it was necessary to correlate their work as well as to progress the considerable number of contracts led directly by the headquarters organization. The progress section of the Parolle Electrical Plant Co. was called on to supplement the headquarters staff and to provide, in effect, a branch office in the North-east of England where much of the manufacturing was carried out.

At an early stage in the contract, it was decided that the main contractor had a special responsibility as regards inspection and Inspecting Agents were appointed in addition to a small headquarters staff.

Plant ordering was initiated by the Contracts Division who prepared specifications in collaboration with the Design Divisions.

At this stage, expenditure was checked against the tender allocation and a record made of the reasons for any deviation.

The long period of training laid down by the UKAEA for staff to be employed on the commissioning of Bradwell resulted in the early formation of a Commissioning Division who embarked upon the production of site testing schedules and procedures, and latterly on the preparation of Operating Instructions. It is likely that no engineering plant has been so meticulously served in this respect and it appears to be a feature of Nuclear Power Stations that an unusual amount of knowledge, experience and care are required in the commissioning phase—now reached at Bradwell.

Several modifications have been completed and the station is now two-thirds complete

HUNTERSTON—Construction and design changes

by A. N. H. BOND, B.Sc., Assistant Contracts Manager
and D. W. T. ANGWIN, B.Sc., A.M.I.Mech.E.,
Chief Construction Engineer, Atomic Energy Division, The General Electric Co. Ltd

EXPERIENCE IN THE operation of nuclear power stations and knowledge gained from research since the time of tendering have resulted in modifications to the original design of the station being built for the South of Scotland Electricity Board at Hunterston. Many of these changes have been in the details of design only and have been easily accommodated. Others have been more fundamental and have involved more important changes to mechanical, electrical and civil aspects.

Graphite

The Hunterston reactor core consists of a large number of columns of graphite made up of alternate blocks and tiles. The fuel channels are circular holes running the length of each column. At the top of the core the columns are bound together by garter restraints whose coefficient of expansion is made the same as that of graphite, but at the bottom they are spigotted into the steel support plates on which the whole core is built.

When it became necessary to design for Wigner shrinkage as well as Wigner growth it was considered that under the worst conditions of Wigner shrinkage unacceptably large gaps could occur between the columns. After the consideration of a number of alternatives, the difficulty was overcome by the adoption of that principle of the GEC design of core for their Japanese reactor which makes it suitable for use under earthquake conditions. The revised design involved only slight modifications to the blocks already prepared, and very little material had to be wasted.

In the original design there were two tiles between each of the moderator blocks, all four components being keyed together by means of edge keys. One double-thickness tile has now been substituted for the two original tiles and circular spigots replace the edge keys. Eight radial keyways are cut in each tile, one at each corner and one in the centre of each side. When the core is built a cruciform key is inserted where the four corners of the tiles meet and a plain key joins the keyways in the adjacent sides. The keys are all free to slide in the keyways and the graphite can expand and contract freely although all columns are interlocked.

In addition, it may be seen that the arrangement permits the centre distance between columns to be varied provided that the change is the same for all column centres. In practice there may be centre-to-centre variations up to the clearance allowed in one set of keys. It may be shown theoretically, and has been demonstrated by GEC by extensive experiments with core models, that the key tolerances are not additive, and also that provided the keys are free to move, the only force required to expand or contract the lattice is the force necessary to accelerate freely supported blocks.

Thus the GEC design not only provides a solution to the problem of maintaining a stable core under conditions of Wigner shrinkage but also overcomes the difficulty of mounting graphite on steel without some form of rolling support.

Another problem which had to be met in the course of design development was that of raising the moderator temperature to avoid a build up of Wigner energy which could be released under operating or transient conditions. A feature of the GEC fuel element is that it is supported in a graphite sleeve, and the original design permitted a flow of gas up the annulus between the sleeves and the channel, thus removing the heat generated in the moderator. By preventing this flow the moderator temperature would be raised to a suitable value. A piston-ring type of seal was therefore incorporated in the support member, thus effecting the required degree of sealing. Revised nuclear data have since shown that the Hunterston reactors are in fact safe at the original moderator design temperatures throughout their lives, but control of the flow up the annulus gives a degree of design flexibility which could well be of use in meeting future requirements.

Cooling pond

Discharged fuel elements in the original design were transported singly to the cooling pond through an inclined, heavily shielded chute. This structure has now been replaced by underground tunnels, through which batches of elements are transported in skips. At the cooling pond in a heavily shielded blockhouse, the skip is transferred to a 'wet' conveyor and the elements are stacked in the egg-box storage skip under water using powered tongs. Damaged cartridges will be 'bottled' under normal operating conditions by a machine which is also housed in the blockhouse, so that contamination of the pond water can be avoided. The storage area is divided into 3 areas; one large area is for use in the event of an emergency discharge and two smaller areas for the normal throughput of the two reactors. The depth has been increased to cater for decreased permissable dose rates and the overall size is now about 100 ft long by 75 ft wide by 30 ft deep.

Graphite sleeve disposal

The graphite sleeves are removed from irradiated fuel elements in the separating room, dropped down a chute into a cracker and broken to reduce bulk. The product is then transported in skips through an underground tunnel

to the Active Solid Waste Disposal Building and here stored in concrete bunkers.

This arrangement replaces the method of incineration originally proposed.

The building will cater initially for 4 years' operation of both reactors, but provision has been made for extensions at a later date to cater for the full life of the station. Should the recycling of sleeves prove feasible at some future time, the handling arrangements can be modified to deal with uncracked sleeves.

Support of pressure vessel and reactor core

In the original design of the reactor pressure vessels each was supported on a cylindrical skirt welded continuously along the junction. An inner skirt, effectively continuous with the outer one, was used to support the reactor grid. A number of mock-ups of the skirt-to-shell welds were prepared, from which it became apparent that although welds of that size and shape could be carried out successfully, the techniques of non-destructive testing were not then sufficiently developed to ensure effective inspection of them.

In the revised design each vessel is connected to its support skirt through 120 gusset plates, which were first welded to the bottom head and slotted to fit over the skirt. After positioning the bottom head the skirt was welded to the gussets. Inside, the reactor grid rests on 60 rollers which are supported on stool plates attached to the vessel by a further 120 gusset plates.

Main gas circuit

Should the station become isolated from the national grid (an unlikely contingency involving coincident faults) the reactors are tripped and the removal of residual heat is accomplished by two gas circulators only, which are automatically switched to battery supplies. The battery has adequate capacity for the operation of two circulators and essential auxiliaries, until standby diesel engines in the turbine hall can take over. Even if, for any reason, it is not possible to run the circulators, the safety of the station is still assured by the inherent capacity of the 8 circuits in each reactor to circulate gas naturally due to thermal effects. This natural circulation has been greatly increased by raising all the heat exchangers 22 ft above their original positions.

In addition, to handle the immediate transient effect, a flywheel weighing more than 8 tons has been incorporated in each circulator drive. It has not been possible to support this large extra weight on the SRU shell itself, and it has therefore been mounted in the concrete supporting structure, about 65 ft above ground level. The motor is mounted on a plinth at ground level and precision ground and honed hollow shafts transmit the power from motor to flywheel and flywheel to impeller via gear-type flexible couplings.

A complete drive has been exhaustively tested on site under conditions closely approximating those under which it will operate, and has proved entirely satisfactory.

Control and instrumentation

Experience in the operation of reactors has brought to light the phenomenon of instability in the core due to spatial variations in neutron flux. To detect and control this, various modifications have been required.

In place of the original single thermal column, three thermal columns are provided, each equipped with neutron flux measuring devices. To ensure adequate control, the core has been divided into a central cylindrical zone and eight radial sectors, each with independently operated control rods, which are actuated so as to maintain constant gas outlet temperature over the whole core.

From experience gained at Windscale the number of thermocouples built into the core has been increased some seven times and now totals more than 900. To ensure that the information available is correctly interpreted and significant trends presented to the operators, all thermocouples are continuously scanned and a printed record of temperatures produced. The thermocouples are switched by mercury-wetted relays and the circuits are fully transistorized. The equipment has been designed and manufactured by GEC Applied Electronics Laboratories, Stanmore.

To reduce the possibility of spurious reactor trips, three 'guard lines' which in themselves are further sub-divided have been introduced in place of the original two. At least two of these sets of series relays must receive an initiating signal before the reactor is tripped.

Should it be necessary to evacuate the central control room due to any unforeseen set of circumstances, provision has been made for alternative display of information which is essential for the monitoring of the tripped reactors.

In the original design the electrical output of the station was controlled by the power setting of the reactors, and this was unaffected by changes in system frequency. A control system now being developed will make the station frequency-sensitive, when this is required, by using the change in h.p. steam pressure at the receiver consequent upon a frequency variation to initiate a change in reactor power.

CONSTRUCTION

The building of one of the first of the nuclear generating stations, with its many novel features of design, calls for a management organization on site not dissimilar to that for any other major engineering enterprise, but with the addition of specialist staff skilled in nuclear engineering.

The Group's staff at Hunterston consists of 30 Construction Engineers; 14 Commissioning Engineers and Physicists; 35 Draughtsmen, Inspectors and Clerks-of-Works; 15 Quantity Surveyors, Administration, Labour Relations, Safety, and Health Physics Staffs; 50 Industrial Staff (Police, First Aid, Fireman, Crane Drivers, Workshop staff, Storemen, etc.).

No hard and fast rules were laid down for the qualifications of the technical staff, but in practice it is found that the majority of the engineering staff positions are filled by qualified engineers. For some appointments it has been found that qualification by experience alone is sometimes better than a more academic qualification. All professional grades in the Commissioning Staff have received some formal academic training, and are qualified engineers or physicists.

The Group staff has been divided into groups or sections, each headed by an engineer with overall responsibility for all work within a particular building, or group of buildings. In addition there are a number of service and specialist departments whose responsibilities cover the whole site. Examples of service departments are the Concrete Quality Control Laboratory, Electrical Service, Safety, and Progress and Planning Departments. Typical specialist departments are Instrumentation, and Clean-

Conditions Inspection. A particular case of a specialized service is provided by the Commissioning Department. There is here a variation in control, since at the stage of fuel loading the responsibility passes from the Group Engineer to the Commissioning Superintendent.

In overall charge of construction and commissioning is the Group's Chief Resident Engineer; below him responsibility is divided through a Resident Civil Engineer, a Resident Mechanical and Electrical Engineer, and, at a later stage, the Commissioning Superintendent. Other departments directly responsible to the Chief Resident Engineer, are Labour Relations, Safety, and Clean-Conditions Inspection. Progress and Planning departments are responsible to the Resident Mechanical and Electrical Engineer, and the Quantity Surveyors are responsible to the Resident Civil Engineer.

Little specialized training of construction staff was found necessary or possible, the staff being recruited in general from men already experienced in construction of large-scale projects such as thermal and nuclear power stations, hydro-electric work, oil and chemical plant, and also from local Authorities.

All commissioning engineers and physicists have undertaken periods of special instruction in nuclear engineering at technical colleges or at the Atomic Energy Research Establishment at Harwell, and, in addition, have had instruction and experience in reactor commissioning and operation at various establishments of the Atomic Energy Authority.

In addition to the GEC and Simon-Carves Atomic Energy Group staff, other divisions of The General Electric Co. Ltd and Simon-Carves Ltd working at Hunterston provide their own supervisory staffs, as also do the various principal sub-contractors.

In many places in a nuclear power station such as Hunterston entirely new techniques of working, or significant extensions of established techniques, are used, and these require specialized supervision and inspection. Examples of these are:

Pressure-vessel fabrication Fabrication on site of large pressure vessels, using thick plate, to the very highest standards of quality, brings problems of recruitment, teaching and qualification of welders; also problems arise of accessibility and habitability during preheat in confined spaces. High standards of non-destructive testing make necessary the use of delicate and potentially dangerous high-voltage X-ray machines. An unusually high degree of accuracy is required in placing nozzles and other openings, and in the application of machine-shop tolerances to boiler-making practice.

Clean conditions For some sections and phases of the construction work, such as the core assembly, it is necessary to establish 'clean conditions' procedures and standards of work which are to most people an entirely new conception. Appropriate education of all those concerned is needed, and the clean-conditions, when established, with the necessary restriction on access, make further demands on planning and staffing.

Site arrangements

Access to Hunterston for plant, materials, and personnel, is entirely by road. A bus service operates to bring the men to and from work and covers an area about 30 miles radius from Hunterston. There is no labour camp.

The total area of the site is 110 acres, of which the finished permanent works occupy approximately 20 acres. Most of the rest of the site is available for storage and fabrication, although 15 acres have been used for dumping of spoil, or are otherwise opened by excavation. A particular feature of Hunterston is that the storage areas have been increased by reclaiming 17 acres from the sea by dumping spoil behind a rock bund. The temporary covered storage available on site is approximately 30,000 square feet, some of this being heated storage for instrumentation. A disused mill in nearby Dalry has also been taken over and converted into a store for graphite and certain other high-quality components.

On site is a large comprehensively equipped shop where steam-raising units are fabricated from rolled plate. As a Group service to all contractors on site there is a small but well-equipped machine and fabrication shop.

There are two laboratories at Hunterston. In the first—the concrete laboratory—a comprehensive batch-testing programme is carried out on all concrete and aggregates used on site, with particular reference to shielding concrete. A further laboratory has been established to serve the Commissioning Department. In this laboratory, foil counting and other measurements will take place during commissioning. At the present time the laboratory is being used for proving and developing the measurements to be employed. Equipment includes a pulse-height analyser which will be used for neutron spectra investigations.

Planning and progress

To some extent the construction problem is alleviated at Hunterston by using a Goliath crane, so enabling prefabrication to take place away from the final situation. Sections of the reactor pressure vessels up to 350 tons are prefabricated before being lifted into position, and the main frame of the biological shield roof of the reactor is constructed of pre-cast concrete beams weighing up to 310 tons.

The main burden of the planning falls upon a Master Planning Section which operates from the Group's headquarters at Erith, Kent. There are some 25–30 Programmes which are approved by the Client and establish certain key dates which must be adhered to. On the site the Master Programmes are broken down into unit programmes. These are detailed, or may in fact be on a daily basis in cases where, for example, many contractors are working on one job at the same time. Within the key dates the unit programmes allow the maximum flexibility to the site organization.

Inspection and supervision

Inspection of material before delivery to site is carried out by a Central Inspection Organization, based on the Group headquarters, working through established inspection organizations in the Group. A double inspection check, where considered desirable, is provided by the Client's staff or his consultants. At site there is a similar double check: primary inspection is carried out by the Group's staff and final inspection and assessment of the work in accordance with the Group's specification is undertaken by representatives of the South of Scotland Electricity Board or their consultants.

After construction or installation, inspection of finished work is carried out to a schedule which is jointly agreed between the Group's staff and the SSEB.

The cooling water intake and choice of pressure vessel steel posed interesting problems

HINKLEY POINT—Construction

by W. WADKIN, M.I.Mech.E., Chief Construction Engineer, and D. F. HUTTON, A.M.I.Mech.E., Construction Department, English Electric, Babcock and Wilcox, Taylor Woodrow Atomic Power Construction Group

INSTRUCTIONS TO PROCEED with construction were received in September 1957; full access to site was obtained in December 1957 and work has since progressed steadily.

Programme

The first step was to produce the master plan indicating the phasing of the major site operations, particularly those which were necessarily sequential since it is these operations which determine the total construction time.

Figure 1 shows a simplified version of a typical master plan for a single reactor outlining the major site operations controlling the overall construction time.

The progress at site reveals all the major features of the project emerging in the sequence originally built into the master plan. The belief that the work outside the main sequence had a degree of flexibility has been confirmed and utilized to secure more advantageous and economic working. Sufficient work was done on the use of models—as an aide to planning, particularly in considering the phasing of permanent and temporary works—to suggest that there is scope for further development in this field.

The skills, effort and care devoted to producing long and short term programmes for site, manufacture and design, can only be fully reaped if there also exists an accurate and consistent progressing system.

The civil works

To make the best use of the site and reduce circulating water pumping costs, it has been necessary to reclaim most of the turbine house area from the Bristol Channel by building a concrete seawall 1100 yards long.

Large construction areas are required adjacent to the permanent works for reactor vessel fabrication, steam raising unit construction, stores and plant maintenance areas, carpenters and steel-benders, concrete mixing plants, camps, canteens and offices. The total construction area at Hinkley Point is about 140 acres against a final station area of some 40 acres (see Fig. 2).

Reactor foundations A compact reactor layout can produce an average loading of between two and three tons/ft², with, of course, very much greater local loadings. Since the degree of differential settlement between the major parts of the plant is strictly limited by the permissible deflections of the gas ducts, most nuclear power station sites exploited so far incorporate massive continuous rafts over the whole reactor area.

At Hinkley Point, however, rock making up much of the site can carry very heavy bearing pressures and, consequently, the main parts of the plant have separate foundations with resultant economy.

Biological shield Even when space is restricted, special high density aggregates such as steel or lead shot, barytes and magnetite will usually allow concrete to be employed on the major works, leaving the more expensive materials such as lead, iron or polythene for special applications.

The dried-out density of the concrete is of the utmost importance, and concrete samples are maintained in an oven at the operating temperature of the shield until repeated weighings establish that the minimum water content likely to be met in the life of the shield has been achieved. This density must, of course, be greater than that on which the shielding calculations were based.

The main biological shield, now complete for both of the Hinkley Point reactors, is a twelve-sided monolithic structure 76 ft wide inside and 95 ft high, the wall being 7 ft thick. The shield is pierced by a large number of holes for gas ducts, control apparatus and mortuary holes and a high degree of accuracy in the placing of the forms and shutters for these holes was essential. The secondary shields, 6 ft 6 in. thick, also complete, are rectangular structures enclosing the main shield but structurally independent of it.

Both main and secondary shields were constructed in 20 lifts each about 5 ft high and each lift is divided into a number of bays, Alternate bays were cast and allowed to cure before the intermediate bays are filled in to avoid undue shrinkage effects. Accurate forming of the 12-sided shield was achieved by setting the timber shutters, adequately braced and supported, to accurately made profile forms supported on an internal framework of scaffolding.

The concrete was placed by means of derrick cranes and skips, each skip holding about two cubic yards. Maximum compaction was obtained by the use of mechanical vibrators of the immersion type.

Turbine house The construction of the Hinkley Point turbine house presents no problems more difficult than those normally encountered in this type of work and the work at site is now nearing completion with steam turbine and electrical installation already begun.

Circulating water system The design and construction of the cooling water intake, sited in tidal water some 2000 ft offshore, presented a challenging problem. This structure is required to introduce into the cooling water system, at

all states of the tide, 85 million gal/h; and the velocity of flow at entry must be restricted to a maximum of 1 ft/s. For the present station the quantity required is 35 million gal/h; and the capacity has been provided to cover future development of the power station. The intake is connected to an onshore pump house by two water tunnels each 11 ft 3 in. dia. and one tunnel 7 ft dia. for personnel access.

The extreme tidal range is in excess of 40 ft, and the position of the intake is exposed to heavy winds and seas. It was, therefore, decided to construct as much of the intake structure as possible in the form of a caisson within a dry dock excavated on the shore line. The basic concrete structure consisted of eight hollow circular columns rising from a circular box beam and tied by three ring beams. To form a caisson this structure was sealed around the sides with sheet piling and at the bottom by a timber floor. Temporary floors of structural steelwork were incorporated to carry the ancillary equipment and temporary cranage. The caisson formed a cylinder 60 ft high, 90 ft in dia., weighing 3900 tons. Within the hollow columns were suspended tubular steel legs which were surmounted at top deck level by 500 ton jacking structures.

In June 1959, the caisson was floated within the dry dock and then towed to its final position. It was sunk on to eight legs which were driven by the jacks into the sea bed to support the unit and to enable accurate levelling to take place. Additional sheet piling was then driven around the caisson to seal into the sea bed. After the caisson had been pumped out and cleaned, the legs were retracted in turn and proper pad foundations inserted. Excavation was then carried out to form the connexions with the tunnels which had been driven from the shore.

The cooling water tunnels have now been connected and the internal concrete work is already largely completed. The intake will be surrounded by guard screens which will be fixed to foundations constructed outside the protection of the caisson. The sheet piling will be finally removed and the structure will appear as an open concrete framework offering a minimum surface to wave action. A concrete deck will be incorporated above high tide level and will accommodate a rotating 12-ton crane for handling, replacement screens and isolating gates for the tunnels.

Reactor pressure vessel

The steel used undergoes extensive and complicated fabrication operations under site conditions and must have good welding characteristics and good notch ductility under conditions likely to be encountered during construction.

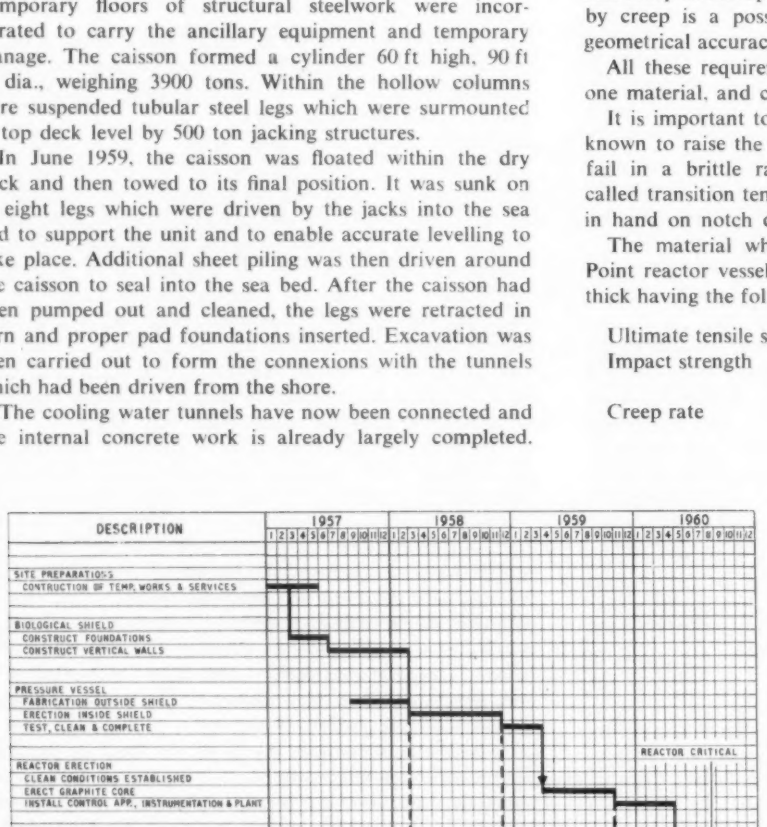
It must also possess a reasonably high resistance to thermal creep at the operating temperature, not because failure by creep is a possibility, but to preserve the long-term geometrical accuracy of the vessel.

All these requirements are not easily achievable in any one material, and compromise is necessary.

It is important to note, however, that irradiation is now known to raise the temperature below which steel tends to fail in a brittle rather than a ductile manner (the so-called transition temperature) and therefore a good margin in hand on notch ductility is highly desirable.

The material which has been chosen for the Hinkley Point reactor vessels is a silicon-deoxidized mild steel 3 in. thick having the following properties:

Ultimate tensile strength	28–32 tons/in²
Impact strength	20 ft lb at −10°C 'V' notch Charpy
Creep rate	< 0·1% creep at 100,000 h at 350°C and 5·75 tons/in²



The major site operations controlling the overall construction time are: (a) Preparation of site, construction of reactor foundations, and construction of biological shield walls. (b) Construction of that part of the reactor pressure vessel which must take place within the biological shield. (c) Erection of the reactor core within the pressure vessel and the installation of control apparatus and instrumentation. (d) Plant testing, loading of fuel and commissioning. (Fig. 1)

Welding inspection Before fabrication the reactor plates are subjected to an unusually rigid ultrasonic examination to ensure that there are no laminar defects which could give rise to expensive difficulties later. All welding inspection on reactor vessels, already completed or under construction in the UK, is based on the Class I Rules of Lloyd's Register of Shipping or those of the Associated (Insurance) Offices Technical Committee, which are practically identical.

Every inch of welded seam physically capable of being radiographically examined is dealt with in this way, the required sensitivity being at least 2% of the plate thickness.

All fillet and nozzle welds which, due to their geometry, are not able to be radiographed, are examined by alternative non-destructive testing methods.

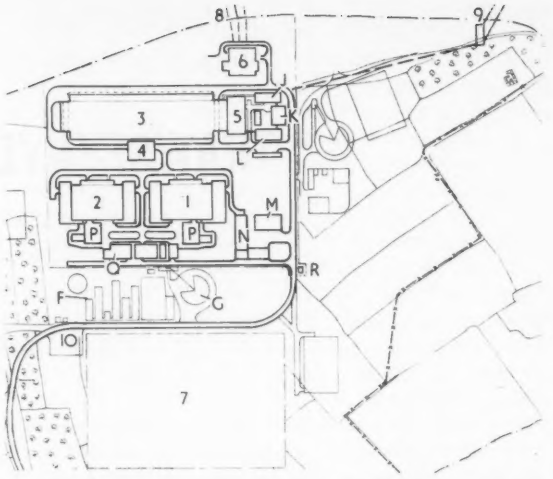
Erection From the master programme, it was evident that the vessel construction time inside the shield directly influenced station completion dates. This fact, led to work inside the shield being kept to a minimum and restricted to welding circumferential seams. The panels of plates were delivered to site by sea and, in the fabrication shop, were built into spherical segmental courses by welding the radial seams. Care was taken to ensure that the periphery of each course matched with its predecessor. The courses were taken as completed into the biological shield and the circumferential seam welded. Experience proved that by building double-depth courses outside the biological shield, a further circumferential weld inside the shield was eliminated and more time saved. With this and the provision of additional fabrication facilities, and without sacrificing course matching, a substantial speeding up was achieved, so that the second vessel was completed in a much less time than the first and well inside the period allowed in the original programme. At Hinkley Point both vessels are now completed spheres and on the first vessel charge and control rod standpipe nozzle work and preparations for pressure testing are well advanced.

Steam raising units

The major problems in the fabrication and erection of the steam raising units are similar to those presented by the construction of the reactor pressure vessels, but they are less severe. The boiler shells are appreciably smaller than the reactor vessels; they are not subjected to severe irradiation in operation.

Nevertheless, the economic consequences of failure could be very serious indeed, and the same care was taken in the selection and testing of the materials, and the same rigid standards of construction were maintained, as for the reactor vessels.

For Hinkley Point, it was felt that there were considerable advantages financially and technically if, at least, the longitudinal seams were welded, X-rayed and stress relieved under shop conditions. As the diameter of the shells is about 22 ft and therefore much larger than can be transported by road in the UK, a wharf has been constructed near the site and complete rings (and in a few cases twin rings) were transported to site by ship. A temporary workshop was provided within the area served by the Goliath crane, and here the rings are fabricated into boiler shells, each 90 ft long. The circular seams are welded, X-rayed and stress relieved locally by electric induction methods, and the complete shells hydraulically tested in the horizontal position. They are finally cleaned by a shot-blasting process, sealed up, lifted into position and then tubed.



1. Reactor No 1; 2. Reactor No 2; 3. Turbine house; 4. Control block; 5. Workshop; 6. Pumphouse; 7. Switchgear compound; 8. C.W. intake; 9. C.W. outfall; 10. Car park; J. Welfare; K. Canteen; L. Administration; M. Diesel house; N. Fuel store; P. Past irradiation fuel stores; Q. Decontamination; R. Police lodge

The tube banks are shot blasted at works, acid cleaned and vacuum cleaned on site in a temporary building and transported in sealed steel containers to the 'clean conditions' chambers installed on top of each boiler shell.

The operation of installing tubes is one of some complexity and delicacy calling for the close operation timing, operation integration quality control and higher standards of overall achievement than is more normally found in a modern works than on a construction site.

At present eight of the 12 steam raising units have been lifted into their final position on the reactor and the shells for the remaining four units are rapidly nearing completion in the fabrication shop and all should be in place before the end of 1960.

Tubing is proceeding on three of the steam raising units and preparations are well advanced to begin tubing on three more.

General

In the turbine house, both the main 40-ton and 150-ton cranes are erected and tubing of the first main condenser is in hand while two other main condensers and the two dump condensers are already erected. Feed heating plant, oil cooling equipment and main cooling piping erection also proceeds. On the electrical section, transformers, switchgear, batteries and station and unit boards are arriving steadily on site and being erected as required.

In the pumphouse forebay the band screens installation nears completion and in the pumphouse work on the six main Drysdale pumps is now well advanced together with the connecting pipework.

In the diesel house the five 900 h.p. diesel engines and motor generators which are to be used as standby emergency supplies are in course of erection.

The laundry is operating, the administration block is complete and general finishing work is in progress in the canteen, welfare block and fuel store, while the effluent treatment block, radioactive waste store and decontamination building are under construction.

Concurrent with the work on site, off-site activities are aimed at completing the substantial equipment programme in order to have the station in operation in 1962.

The inaccessible site necessitated careful planning and integration of workshops

TRAWSFYNYDD—Construction

by J. N. BISHOP, B.Sc., M.I.Mech.E., A.M.I.E.E., Chief Construction and Commissioning Engineer, Atomic Power Constructions Ltd

THE CONTRACT FOR THE construction of Trawsfynydd Nuclear Power Station was awarded to Atomic Power Constructions Limited in June 1959, and entry was made to the site on July 1.

Most of the work undertaken in this 15 months has been that of site clearance and preparation of the major excavation work, levelling of the switching compound and the completion of the foundation work on the reactor buildings and the turbine house. At the north end of the rather restricted site, the initial effort by the civil engineering contractors was directed to the preparation of the large level areas required for the workshops and factories needed for the construction of the boilers and pressure vessel, and building the track and construction area for the Goliath crane. The site itself is on the north side of an artificial lake which acts as a head water for the hydro-electric station at Maentwrog. The site sloped considerably to the north east and a great amount of broken rock had to be removed before the foundation work could be started. In the finished station, the turbine house and the reactor buildings will be on a terraced level some 40 ft higher than that of the switching compound.

The circulating water system is unique for the UK in that it uses natural radiation from the surface of the lake to cool the water. Before the main work of the power station was started, a separate contract was made for building the training walls in the lake, which link the existing islands and ensure that the hot water leaving the condensers is circulated around the periphery of the lake before being drawn back into the circulating water intakes.

Site access

The main access to the site is from the main Maentwrog/Dolgelley road and all material is brought to the site along this road. There is no rail access and the roads in the immediate area were unsuitable for industrial loads and a considerable rebuilding programme was put in hand before work on the station started. The access problem was aggravated by the bridges in the North Wales area being inadequate to carry the heavier components of the power station.

It was, therefore, decided to re-open Portmadoc Harbour, which has not been in general use since the decline of the slate trade and has been completely idle since the war. It was necessary to strengthen one of the existing quays and carry out extensive dredging work to ensure that a ship of 11 ft draught could enter the harbour. Even with this restriction, access to the harbour can only be obtained during the few favourable tides each month and the departure of ships from Birkenhead or London has to be tightly programmed. The main components at present being delivered through the harbour are the strakes for the boilers and these are unloaded by a temporary crane which has been installed on the quay. This is to be replaced very shortly by a permanent crane capable of lifting the heaviest loads anticipated, such as the alternators and transformers.

The road from Portmadoc to the site has been widened and strengthened and this involved the whole rebuilding of the stretch of road between Maentwrog and Trawsfynydd in order that a loaded transporter and trailer could ascend to the site which is some 650 ft above sea level.

Site workshops

The site workshops that have been erected are of a higher standard than those of other power stations. This has been brought about because the position of the site and its limited access has placed a great restriction on the size of the components that can be carried to the site and because the Goliath crane will be used to lift the largest possible components into place. Large sections of the pressure vessel, the gas ducts and the concrete building will be lifted into place, and, as is normal at those sites with a Goliath, the boiler shells will be lifted on to the plinths ready for tubing.

The main site boiler fabrication shop is now in full use by International Combustion Limited. It is constructed in two levels, necessary because of the slope of the ground. In the lower section, the boiler strakes are received and are welded into pairs by automatic manipulators and then lifted to the higher level where four such pairs, together with the end caps are welded to form a complete boiler shell. The upper level of the fabrication shop is used to construct the large components of the gas ducting, the sections of the shield cooling ductwork and the other large prefabricated components which are being made by the boiler contractor.

The fabrication of the pressure vessels is now well in hand by Babcock & Wilcox Limited in the fabrication shops. The construction of these vessels will be undertaken in three areas; there are two shops which are of a semi-permanent type, giving working conditions equivalent to that obtained in a factory, and a prepared area within the biological shield. Sections of the pressure vessel are made in the shops consisting of two or more strakes and when they are completed and, if necessary, stress relieved, the roof is removed from the shop and the section of the vessel transported by the Goliath crane and placed within the biological shield.

The cooling annulus for the concrete of the shield has been erected comparatively early in the programme and, while it serves as an inner shuttering for the concreting of the biological shield, it also forms the walls of another pressure vessel fabrication shop. This shop, too, is fitted with a removable roof. This arrangement of working areas

enables large components of the pressure vessel to be fabricated within the fabrication shops and it is expected that the heaviest load to be lifted by the Goliath crane will be about 400 tons, which will be the weight of the top dome of the vessel complete with its nozzles. Experience has indicated that a spherical vessel can be successfully built in this way as close control can be obtained over the welding shrinkage of adjacent strakes and the consequent accurate matching of the circumferences.

A considerable amount of precasting of concrete is being undertaken at the Trawsfynydd site and, in addition to the normal precasting of beams for the floors and of stanchions for crane rails, advantage is being taken of the knowledge of the contractors, Nuclear Civil Constructors Limited, in the field of reinforced concrete work. In order to carry out the work, special prefabricating shops and areas are being brought into use.

As soon as the top dome of the pressure vessel is placed within the biological shield, the concrete of the shield will be continued upwards to form a large corbel and it is on this corbel that a pre-cast concrete grid, which forms the basis of the uppermost biological shield, will be placed. This will weigh just under 400 tons at the time of its lift. The standpipes will be supported from this grid and accurately aligned before the final casting of the concrete in the holes of the grid.

The north end of the Goliath track has had to be supported on tiers some 40 ft high reaching down to solid rock before the space between the tracks was backfilled to give a level working area. The crane spans the two shops in which sections of pressure vessel are made and also the despatch bay and stress relieving bay of the boiler fabrication shops.

At the south end of the site, the Goliath crane spans another construction area where the prefabricated grid for the upper biological shield is being made, together with the removable roofs for the pressure vessel shop within the biological shield.

Supervision of the work

In order to provide adequate control, it was considered by APC that an entirely separate staff was essential to supervise and correlate the efforts of the separate contractors. It was a matter of APC policy that the member companies of the Consortium would work for APC and that the APC standards of inspection and acceptance of work would be such that the work would be immediately acceptable to the Electricity Board. This would enable the customer to maintain an economical minimum of staff on the site.

To this end, a comprehensive staff on site has been built up from day one. This staff is illustrated in Fig. 1, from which it will be seen that the site is controlled by a Resident Manager and the work is divided into three branches under his direct control. One of the Deputy Resident Engineers controls all the work in the reactor area as it is essential that with such a section coordination of electrical, mechanical and civil engineering the day to day supervision must be centralized. The other Deputy Resident Engineer takes full responsibility for the engineering in the turbine house, circulating water works and other work under construction.

The site administration officer controls the normal clerical and accountancy services experienced on a site of this magnitude, together with the organisation of the transport and site security.

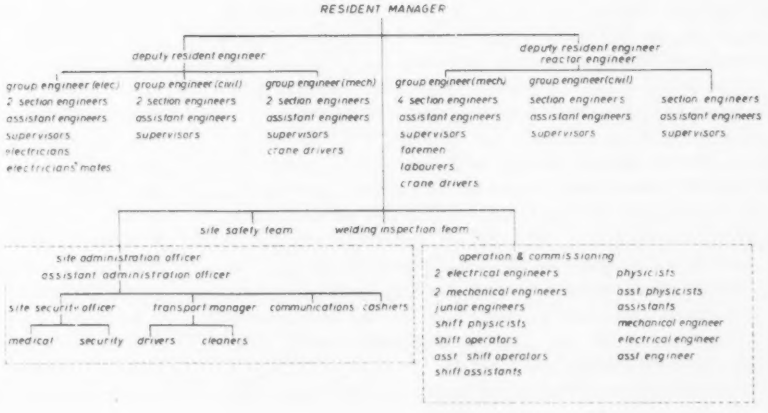
In addition to the normal chain of command, the site safety officer has been appointed with direct responsibility to the Resident Manager. He is assisted in his duties by a representative of each of the main Contractors on the site and this team works to ensure that all site activities are undertaken with a minimum of danger to personnel.

A team of welding inspectors has been appointed reporting direct to the Resident Manager. It was considered advisable for the station to have a team of people who were not immediately connected with production, but could ensure that standards of welding were maintained and could act as advisors in all cases where difficulties were being experienced. Both the safety teams and the welding engineer receive guidance direct from head office, as it is considered that they should be able to advise the Resident Manager on their particular work from an independent viewpoint.

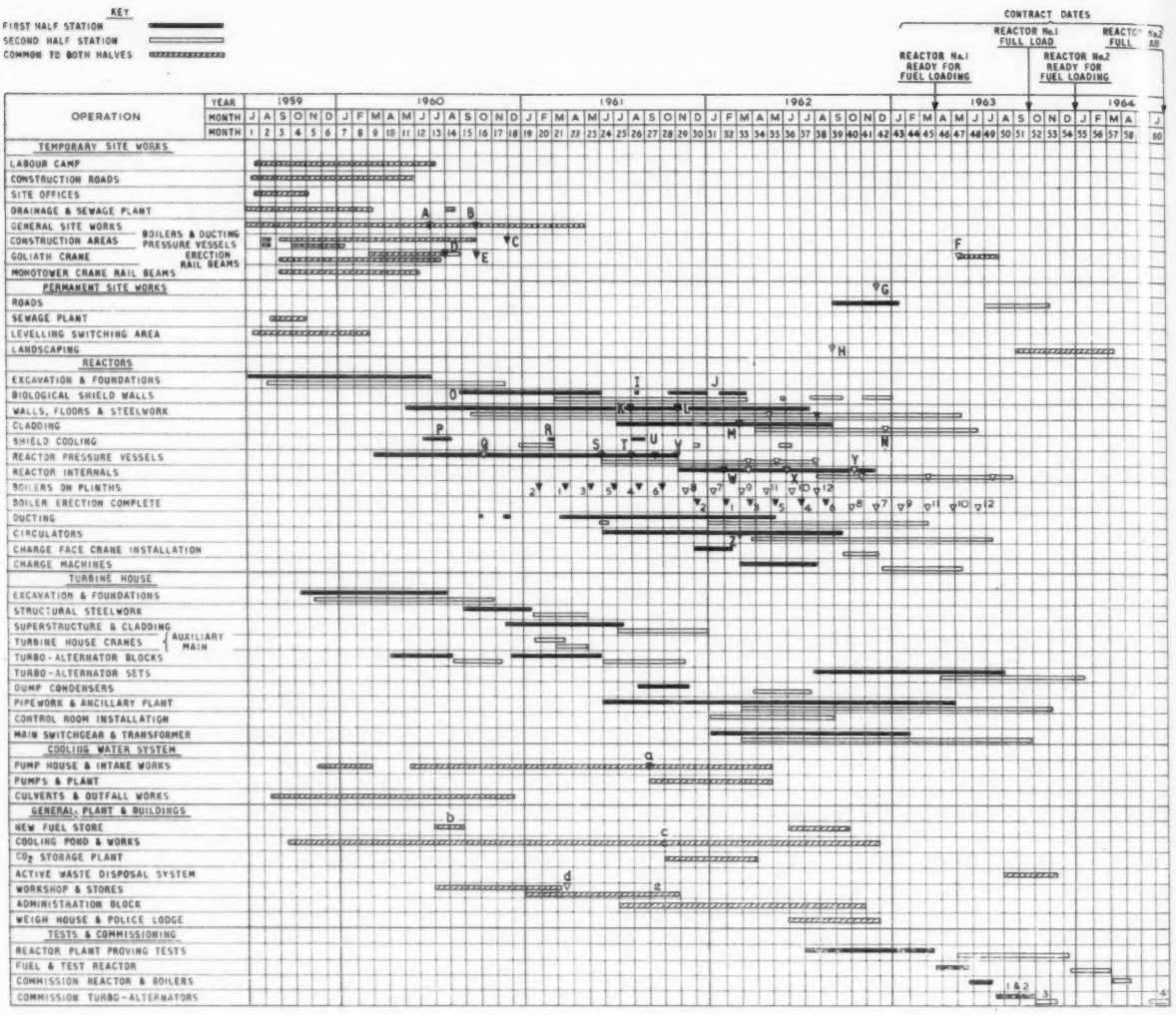
None of the APC staff on site was previously employed by any of the main contractors, as it was felt that in order to give a good service to the customer they must have an unbiased viewpoint.

Programming the work

A programme is shown (Fig. 2) giving the outline of the construction work at site. There are certain erection steps in the building of a nuclear power station that must perforce follow each other. It is this sequential erection that



The site is controlled by a Resident Manager and the work is divided into three branches under his direct control (Fig. 1)



Master programme for Trawsfynydd (Fig. 2)

makes the construction of a nuclear power station different from that of a conventional station. The most important of these sequences is that involved in the building of the reactor itself, wherein there is a chain of events that must be adopted. First establish the foundation for the pressure vessel, construct the vessel, stress relieve and pressure test, followed by establishing clean conditions; lay the graphite and instal the burst cartridge detection equipment; carry out all the necessary checks and then start fuel loading. This sequence takes about three years and no one step can be taken until the one before has been completed.

The only ways available for reducing the time of this work are by prefabrication—and this is only possible in respect of certain components of the pressure vessel and is very difficult for the equipment within the vessel—and by careful planning and rehearsal of the work. As far as Trawsfynydd is concerned this detail planning and rehearsal of reactor construction is well in hand by Fairey Engineering Limited and several 'mock-ups' of the critical areas and the layout of the erection equipment within those areas, have been made and tried out.

The remainder of the power station is more easily programmed. The turbine house is a unit in its own right, and its construction progress does not affect the remainder of the site. It could be, as at Trawsfynydd, that the circulating water system primarily associated with the turbine house can affect the access to the reactor buildings; but this is a matter of advancing the work, so that, although it is ready some two or three years earlier than necessary, the construction of the reactor buildings can proceed unhindered. The boilers and gas ducting are closely tied in with the construction of the reactor buildings, but the time scale is such that the limitation is imposed by the reactor construction sequence. The major problem imposed by the boilers and ducts is the close integration of the mechanical, electrical and civil engineering work, so that the various components are fed into the building at the correct time and it is this close integration that makes the construction of a nuclear reactor such a different proposition from any other major constructional job.

In order to ensure that items of plant are delivered to site at the correct time, it has been necessary to set up a team of engineers to coordinate the efforts of the subcontractors, and to progress the work in their factories.

The SM 50MW research reactor

This projected Russian reactor will provide intense beams of fast and thermal neutrons and gamma rays for research. It operates by using epithermal neutrons and has a sufficient reserve of reactivity to allow experiments to be carried out in all the experimental channels and loops simultaneously

SOME DETAILS of the engineering decisions underlying the design of the SM reactor were given in a recent issue of the Russian atomic energy journal *Atomnaya Energiya* (*1*).

The economy of a research reactor depends to a large extent on the magnitude of the ratio of the maximum neutron flux to thermal power. It has been shown that this ratio can be considerably greater in a reactor operating on intermediate neutrons (*2*). Other advantages of such reactors are that a smaller core can be used and construction materials are allowable which permit a high neutron flux. Another important advantage outlined in the article is the long operating period. At 25% burn-up the SM reactor can operate for 60–65 days. With partial replacement of spent fuel and the burn-up held at a mean level of 12·5%, the operating period is 40 days without recharging. A reserve of spare fuel elements stored within the reactor allows this.

The SM reactor (see Fig. 1) has five horizontal, one inclined and three vertical channels for experimental work.

The horizontal channels, in the plane of the mid cross-section of the core, extend into the laboratory. They are shielded and experiments can be handled while the reactor is on power. The shielding and channels can be put under vacuum if required. Flux at the outlets is of the order 3×10^{10} n/cm² s.

All the vertical channels, except one in the centre, are in the reflector, at various distances from the centre. There are seven water-cooled channels, five gas-cooled channels, one channel which can be cooled with helium or liquid hydrogen for low-temperature work, a gas-cooled channel for extremely high-temperature work and one cooled with liquid metal.

The reactor uses plate-type fuel elements and there is provision for storing fresh and spent fuel element assemblies above the reflector. Fuel is shuffled with the reactor on load by a remotely controlled handling mechanism located under the upper endcap of the reactor. It has two movable arms, each serving one half of the core.

The pressure vessel is of welded construction, using type IKh 18N9T stainless steel 36 mm thick. Five pipes are welded into the cylindrical portion of the shell for the horizontal channels and two inclined pipes are welded above the reflector—one of these for unloading fuel elements and the other for the liquid metal cooled facility. Eight pipes in the lower endcap are for cooling water inlet and outlet. The flat upper endcap facilitates the installation of the experimental channels. There are also various holes for control rod drives, drives for the loading and unloading mechanism, etc.

The beryllium oxide of the reflector is contained in a stainless steel shell 25 mm thick which also serves as an additional shield. The reflector is divided into eight sectors separated by zirconium sheets. Internal shields divide the reactor into an annular space and a core space. Water enters this annular space through four ducts welded to the bottom endcap and then divides; part goes to the reflector and the rest between the shields and the reactor shell. At the top, the water recombines and flows down through the fuel element assemblies, leaving the reactor through four central ducts in the bottom endcap. Water flow through the reflector is regulated. The cooling water is monitored from a system of impulse tubes on the underside of the fuel element bedplate. The number of impulse tubes is reduced by use of the coordinate system of sampling.

The control system consists of two automatic regulators with twin rods, four compensating rods, and four emergency rods which can also be used as compensating rods. The automatic control system can maintain the power level at any level between 0·5 and 100% and is controlled by 13 ionization chambers located outside the reactor shell. The safety rods are controlled by three lead shielded ionization chambers.

SM CHARACTERISTICS

Type intermediate heterogeneous pressurized water with pressure vessel
Power 50 Mwt
Max. neutron flux $2{\cdot}2 \times 10^{13}$ n/cm² s
Flux in reflector 5×10^{14} n/cm² s
Ratio of flux to thermal power $4{\cdot}4 \times 10^{16}$ n/cm² s kW
Fuel enriched to 90% U-235 (box subassembly containing 54 flats of 0·5 mm spaced at 1·65 mm)
Moderator H_2O
Reflector BeO (side)
Coolant H_2O (max temp 100°C)
Total volume of reflector 485 litres
Total volume of experimental facilities 43 litres
Normal loading (20 subassemblies at different stages of burn-up) 11·7 g U-235
Mean power rating at nominal power 2100 kW/l
Max heat flux at fuel element surface $5{\cdot}5 \times 10^6$ kcal/m² h
Max fuel element surface temp 195°C
Pressure 50 atmos
CW velocity in core 9 m/s
Total coolant flow 2000 tonnes/h

Research programmes

1 *Production of new transuranic elements*
2 *Investigation of the properties of fissile and construction materials under irradiation at various temperatures (20°K–2000°C) and in various media (gases, water at pressures of 50–350 atmos., liquid metals etc.)*
3 *Investigation of the spectrum of intermediate neutrons*
4 *Investigation of the gamma ray spectrum of the (n,γ) reaction*
5 *Study of short-lived radioisotopes*
6 *Investigations into the properties of neutrons*

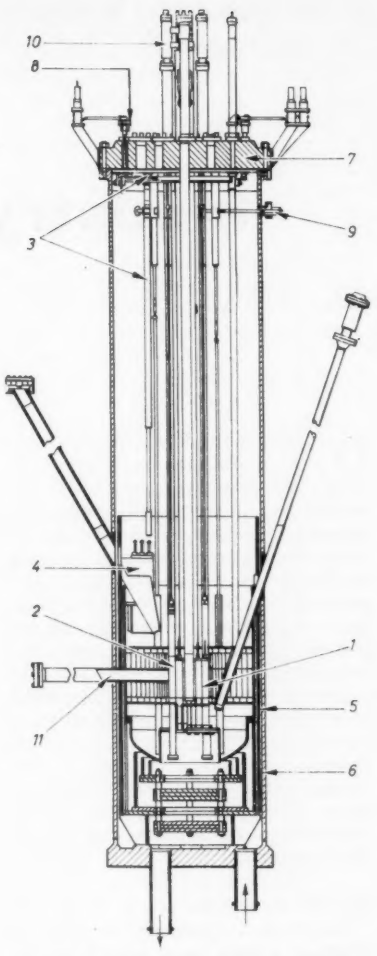


Fig. 1 1—core and reflector; 2—control rods; 3—internal fuel handling mechanism; 4—reserve boxes for fuel elements; 5—shields; 6—reactor shell; 7—top plate of reactor; 8—hermetically sealed outlet of fuel handling mechanism; 9—seals of control rod mechanism; 10—emergency control rod drive; 11—horizontal experimental channel.

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Frank opinions by leading executives on export prospects and their thoughts on official policy

Industry's view on exports

answers to a Nuclear Power *questionnaire, reported by the News Editor, SIDNEY HOLLANDS*

DISAGREEMENT WITH THE Atomic Energy Authority's attitude over small reactors and the need to develop another reactor type is expressed by the executives sounded by *Nuclear Power* in its survey of their personal opinions on the prospects for exports in the near and long term. The general feeling is that there is practically no export market in the next six years for large magnox stations and that exports themselves have been hampered by concentrating on one type of reactor alone—and large ones at that. This feeling is reinforced by most of the replies which stated they disagreed, some vehemently, with the AEA's views on the development and sale of small reactors.

General comments

The general agreement in reply to Question 1 that there would not be an export market in the next six years is perhaps summed up best by the following: 'If by a good "export market" is meant a market of sufficient magnitude adequately to repay the proper proportion of development costs, overheads and manufacturing costs attributable to the project, this is not likely to materialize in the next six years. A few reactors may be sold but it is unlikely that these will turn manufacturers' present losses on nuclear power into worthwhile profits —or indeed into profits at all'.

'Hopes for the export of an AGR or for a small gas-cooled reactor were remote most thought' but a major difference of opinion arose over the short term market for research reactors, components and know-how, These two statements perhaps illustrate this: . . . 'I think there will always be a fair market for research reactors from the smaller manufacturers but it won't be easy work and I don't think anyone will get very fat on it', and . . . 'I do not foresee a big demand for research reactors until nuclear power has become economic in several overseas countries'.

Long term prospects

The long term market for the UK with the HTGC and fast breeder and other types of reactor was generally held to be good. There was a definite 'No' in one reply for the following reason: 'The HTGC design will be common property to West Europe and unsuitable for underdeveloped countries. Similarly, the fast reactor will only be of interest to countries with a large nuclear industry, such as France, which will make their own fast reactors'.

There were several warnings in the replies which held that these types had a potentially good future. The market could only be captured, said one, if we began immediately to diversify our research into promising systems. We were rapidly losing our time advantage over competitors such as the Germans through clinging too long to the magnox line.

Other points of view were: 'The main criterion as to the type of reactor most in demand will almost certainly be economy of operation. This may well permit an integrated programme of natural uranium and fast reactors', said one. Another pointed out: 'I think there must certainly be a long term market for fast reactors but there is a long way to go beyond over-complicated and extraordinarily expensive designs such as Dounreay. . . . If progress on the Dounreay design is anything to go by, I don't think we can expect much from the Authority although its sixth annual report holds some promise. I do not know what can be done to keep the Authority pressing on. I hope we shall not find ourselves driven to licensing agreements, imported from the US'.

Over the question of research reactors, components and know-how, another split occurred. A steady long-term market was envisaged though good salesmanship would be required. However, one stringent comment was that British industry in these fields was too unadventurous and concerned mainly with production line jobs.

Other reactor types

On Question 3, the majority was again in favour of another or two more reactor types being developed by the UK. Those against, however, pointed out that the UK was already committed on a programme of gas-cooled

A short questionnaire was sent to 22 chief executives in the consortia, consulting engineers and leading nuclear firms; 20 replies were received of which 14 were detailed. The six questions asked were as follows:

1. Do you think the UK can still find a good export market in the next six years for any of the following? Which of them offer the most promising market: (a) large magnox power reactors; (b) large AGR power reactors; (c) small gas-cooled power reactors; (d) other types; (e) research reactors; (f) reactor components and ancillaries and (g) 'Know-how' and licensing agreements.

2. Do you think there is a long term market for the UK in: (a) developments such as the HTGC or the fast reactor; (b) other types of power reactor; (c) research reactors; (d) reactor components and ancillaries and (e) 'know-how' and licensing agreements?

3. In your opinion, should the development of reactor types, other than the gas-cooled, be speeded up in the UK with a view to export possibilities? Which types would you recommend?

4. Do you agree with present AEA views on the development and sale of small power reactors?

5. Do you think export possibilities could be improved by any particular changes in Government or AEA policy? Please specify.

6. Any other comments?

reactors and it had considerable development potential. The country's limited resources should be confined in the main to exploitation of this type. It would be uneconomic to develop additional types and 'it is doubtful whether any new reactor type would fit export requirements any better, if as well, as the gas cooled reactors'.

But supporters of other types (the BWR and OMR were the most popular), felt that these should be developed, and as soon as possible. One reply pointed out: 'It is now two years since the AEA stated that the country has the capacity to develop a second reactor type in parallel with the AGR. This new type has not, so far, appeared. If the AEA cannot make up their minds, private industry should be allowed the opportunity to propose systems'.

PWR and BWR types seemed to be the most promising because of their predominant use of conventional materials and techniques, said another reply. Another, while advocating the BWR and OMR, added that the only way to develop is to build reactors and set them to work. It was probably cheaper and certainly quicker to build small reactors than to employ vast numbers of people to develop reactor systems on paper.

AEA disagreement

'I do not agree'; 'Emphatically no!'; 'Their views are negative'; 'Not aware of any positive views of the AEA'; these were some of the comments from those against the AEA's line on small reactors. And it was this subject that most of the replies dealt with at some length. Some of these are as follows:

. . . 'Their views are negative. I do not think I can go along with them on this. I am quite sure that some small plants will be needed and someone will have to build them'.

. . . 'The AEA policy seems to be completely negative. They are not actively hostile to the activities of firms engaged in promoting this type of reactor but they give far less support than might be considered appropriate from a body supported by public funds. It has in fact been said by a responsible member of the AEA—perhaps not as an official pronouncement but doubtless as an indication of their underlying opinion—that they are not concerned with encouraging export sales'.

. . . 'I do not agree with the present AEA views. This decision has probably already lost us our time advantage over European competition because I am sure that most countries during the 1960's will be buying small prototypes rather than full scale stations. By the time we have recovered from this error in leadership, the Germans, Italians etc will probably have overtaken us'.

. . . 'I am not aware of any definite view of the AEA of this subject. My experience is that their thoughts are becoming more and more conditioned by comments and criticism from industry. It is because of such comments that the AEA are now more cautious in their statements about the economic prospects for the AGR. They have almost stopped work on the steam generating heavy water reactor'.

INDUSTRY SAYS . . .

- *Short term export prospects are poor*
- *Develop further reactor types*
- *The AEA should think again on small reactors*
- *Reasonable prospects for research reactors*
- *A long term market for the HTGC and fast breeder if development is speeded*
- *A Government export policy is needed*

Those supporting the AEA say its views on the development and sale of small power reactors are completely logical and based on extremely sound economics. Another comment was that there was nothing to offer that was attractive anyway, while another said he understood the AEA felt that exploitation of small power reactors had to proceed somewhat slowly until the AGR and associated experiments had advanced somewhat further. He continued: 'I would certainly agree with this policy, provided the time scale is not too extended'.

Official policy

Practically all the replies linked together questions 5 and 6 with the main thread running through the answers being that both the Government and the AEA should do more to help exports. 'Industry should be given more development contracts' was one answer. 'Export possibilities would almost certainly be improved if the industry could be assisted by long term loans to prospective customers.'

. . . 'Effort should be concentrated and industry given the chance to compete in uranium enrichment, heavy water production and fuel element fabrication. . . . AEA information and 'know-how' should be made freely available to British industry. . . . The commercial secrecy policy of the AEA with all the palaver of Access Agreements results in much AEA work being wasted because it does not reach all those who could make use of it. . . . The AEA has lost both impetus and sense of purpose and needs the spur of competition'.

. . . 'The organization which has done the greatest damage to Britain's nuclear power exports is, of course, the CEGB. By their preoccupation with size as a method of reducing unit costs, they have tied up the whole of Britain's engineering effort into achieving goals which are truly useless for an export industry. . . . Our only course now is to allow more freedom for private industry to develop its own systems backed by AEA resources rather than using industry's resources to back the AEA's stagnant ideas'.

. . . 'I think it would help any export business in British designed reactors if full facilities for purchase of fuel were available, if required, under conditions and prices which demonstrated full confidence in the fuel and the reactor system. At the moment we seem to lack enough experience to demonstrate our confidence even in magnox reactors by the terms of our fuel offers and we cannot offer enriched fuel for later designs. The fact that we have neither built a large isotope separation plant nor negotiated an agreement to buy American enriched uranium seems to indicate that we still consider the way to enriched fuel is by plutonium. Yet we have made no practical move to investigate the alleged difficulties, particularly economic ones, of plutonium recycling'.

. . . 'I would have thought that a land-based marine prototype would be an excellent project to develop for both a marine reactor and a small power station for use overseas. The cost of such a prototype and the associated development work need not exceed £M4 which I feel is a comparatively modest investment'.

. . . 'They (the Government and the AEA) must develop a firm and unequivocal line on fuel element prices and guarantees. Until about a year ago, AEA statements on fuel prices were very vague and certainly not reassuring to prospective customers who were trying to calculate their generation costs with some accuracy. This, of course, is difficult to avoid until we have some experience with long term irradiation of fuel. It may be necessary for the Government to give firm guarantees without irradiation experience simply in order that we can get established in some corners of the overseas market. . . . The AEA are prone to ask for many luxury items not strictly essential to the safe and economic operation of the reactor. All these extras cost money and time and inevitably cause some concern to the customer who wonders if they are all that necessary'.

A detailed look at a potential customer's attitude to nuclear power and the problems that have to be faced

Buying a nuclear power station

by R. F. W. GUARD, B.Sc.(Eng.), A.M.I.Mech.E., A.M.I.E.E.,
Chief Engineer, Nuclear Dept., Kennedy & Donkin

WHO BUYS NUCLEAR power stations? This is the first question the Overseas Sales Manager of a nuclear group has to answer. In Britain and France, the customer is a nationalized Electricity Authority but in other countries, national ownership of power generation is the exception. When electricity is in private hands there is a reluctance to take risks; even in countries where the power is partly state and partly private, the element of competition does not necessarily eliminate a conservative approach to new developments which involve a heavy capital outlay. This is probably the chief reason why there was no overwhelming rush to buy nuclear power straight off the drawing board in 1957.

In order to try to present a complete picture of a country's attitude to nuclear power today, we might look in detail at the approach of one particularly small European country. No one country can be regarded as typical, so the fact that Ruritania is entirely fictitious need not prevent it from being a useful example.

Power in Ruritania

Ruritania has a fair proportion of hydro-electric capacity which is now fully exploited; that is to say the cost of harnessing any of the remaining streams would not be repaid by the small amount of energy which could be generated. This hydro-capacity is not entirely reliable. In a good wet year, almost all of the country's demand can be met throughout the winter and spring. In a bad year, over half the total energy generated comes from thermal stations.

There is a small coalfield which can supply about one-third of the country's fuel requirements and the remainder is imported. The contribution made by fuel oil is growing rapidly.

The power companies are four in number and are privately owned. High voltage transmission lines are built and run by the Central Electricity Board which is responsible to the Government and which influences policy a good deal from the point of view of transmission and tariffs.

Basically then, the country is an importer of energy. On the whole, the power companies are fairly happy about the general situation today. They have contracts for coal and oil at very favourable rates—certainly lower than would have been thought possible ten years ago. There are no immediate signs of this situation changing.

From the point of view of nuclear power, we may discount the Ruritanian Atomic Energy Commission, which was set up by the Government some years ago under the chairmanship of an eminent Nobel Prizewinner. The Commission advises the Government on isotopes, radio-activity and fall-out, and they operate a swimming pool reactor (American make) at their research establishment. They have a large staff of highly qualified scientists but no engineers.

Much more important is the body known as RURATOM. This was set up as a study group and is a limited company with a large Government holding. All the power companies are participating as well as most of the larger manufacturing industries. The permanent staff is small and energetic, and the presiding genius is Dr Schmoll, who has been behind every sensible decision made in the country concerning nuclear power.

TABLE 1 *Comparison of methods of losing money on nuclear power*

LARGE BRITISH GCR	SMALL BWR
Assume that the loss is no greater than that accepted at present in the UK. Cost of energy from Dungeness or Sizewell, 0·6/0·65d/unit. Cost from a new thermal station, 0·51 pence. Assume loss of 0·1 pence per unit.	Running cost for the Kahl plant has not been officially quoted. Its capital cost and expected burn-up are known, so it is easy to make an estimate. The capital charges will be about 0·65 pence and the fuel cost about 0·6 pence.
Output = 200 MWe	Output = 15 MWe
Cost/kW = £120	Cost/kw = £200
Loss per unit = 0·1 pence	Loss per unit = 0·74 pence
Units generated per year = 13×10^9	Units generated per year = 1×10^9
Loss per year = £5·4 million	Loss per year = £3·1 million

Early planning problems

If Ruritania continues to expand industrially as she has been doing, then every single kilowatt of generating capacity installed must be in a thermal power station and the fuel must be imported. Should this fuel be oil, coal or nuclear? Dr Schmoll argues that it should be nuclear as he believes that within ten years, nuclear power will be clearly more economic than any other form of generation and that the sooner the country gets to grips with this new and difficult technology, the better. His opponents argue that there is not any hurry to turn to nuclear power; modern conventional stations are cheap, efficient, quick to complete and fuel supplies are assured. There will be time to think about nuclear power if a fuel shortage appears to be on the way.

View shared

The view of Dr Schmoll's opponents is shared by most countries in the world today. They are not prepared to make a large investment in something which carries an element of risk. However, this article would stop at this point unless we assume that Dr Schmoll has been successful in persuading the Government to let him go ahead with a nuclear power project.

The first question is, what size of plant should be built? Natural uranium reactors become seriously expensive in sizes less than 100 MWe. It would be better to choose a station of 200 MWe upwards because this is the size now being built in Britain.

But there is not such a restriction on enriched reactors, which can be fairly efficient even when much smaller. A good example is the Kahl station which is now being commissioned at Frankfurt. This is a 15 MWe plant with a BWR reactor (closed cycle) whose construction cost is said to be about £3 millions or £200 per kW. It will produce expensive electricity; but is it necessarily the most expensive to build if one wishes to minimize the amount spent on nuclear power experience?

The calculation in Table 1 is highly simplified but the figures are reasonable. They indicate that a lower annual loss will be made on the smaller plant. For this reason, it is likely that any new power plant project begun in Europe during the next few years will be a small prototype rather than a full scale station.

Establishing the station

Let us assume that Ruritania chooses to build a large station. There are many arguments in favour of doing this; the most convincing one is that if the cost of conventional power increases even slightly, the position will quickly be reversed and the large nuclear plant may suddenly become economic. The small one will always run at a heavy loss.

Dr Schmoll therefore decides to go out for competitive tender for a plant of 200 MW net electrical. For this he will need about £25 million and we will not discuss the means by which he gets it. A fairly high proportion will have to be raised on the open market where high interest rates must be assumed. This means that the capital charges may be twice those applicable in Britain.

The next thing to do is to select a site. This must be chosen with respect to the load demand and the existing transmission system in addition to the usual requirement of being remote from any large city. A block of power of 200 MW may present a system design problem in many countries where it represents an appreciable part of the interconnected network. It must be expected that, in the early days of commissioning, there will be a number of unexpected reactor trips and the station must be backed up by other stations which can accept an immediate and sudden demand totalling the capacity of the nuclear station. This is not a serious problem when hydro power is available.

Most countries in Europe have already chosen a site for their first nuclear station and some of these have been explored with great care.

Specification

An Invitation to Tender will now be prepared and this will be accompanied by a Specification. A good Specification tells the manufacturer exactly what he is tendering for and should also act as a legal document which can eventually form part of the contract; the Tenderer signs a statement '. . . offering to supply . . . in accordance with the Specification and Conditions of Contract'. The terms of the contract should be laid down by the Purchaser although the Tenderer can always state those clauses he is unwilling to accept (at his own risk).

The primary object of writing a Specification in detail is to ensure that every tender includes the same quantity of plant built to the same standards of quality. There must be a careful definition of terminal points and a list of standby and spare parts required (an extra charge machine can cost £1 million). Workmanship and materials are in some cases adequately covered by national standards, but where these do not exist reference may be made to British or American standards, or the clauses may be specially written.

The ideal specification would produce tenders which are mutually comparable without adjustment and which lead to a contract which is unequivocal and involves neither parties in extras or losses due to misunderstandings. Such an ideal is probably unattainable on a large project but it remains as the target.

At this point, Dr Schmoll gives serious thought to a fundamental question. Should Ruritania buy a nuclear station as a straightforward commercial operation with full guarantees and a fixed price? Or should a collaborative agreement be negotiated with the chosen contractor so that a joint binational design and construction team is set up in Ruritania, using British know-how, but with most of the contractual work done locally? The latter alternative is attractive to the industrial interests and by now, most reactor manufacturers will gladly accept such an arrangement even though it minimizes the contribution they make in actual components. However, it also means that Ruritanian industry will shoulder many of the responsibilities for design, workmanship and delivery of equipment and many of the guarantees which the tenderer would normally offer cannot be enforced.

The scope of the work

We will assume that Ruritania decides to buy the whole of the nuclear generating plant under a single contract. In Britain, the stations purchased to date have been complete, containing everything necessary for the generation of electricity up to the H.V. connexions or other convenient terminal point. The purchaser simply provides a large field near a source of cooling water, and the entire project is then handled by a Consortium.

Ruritania is certainly not going to want this type of contract. She is interested in the maximum local manufacture possible because RURATOM contains a large representation of the country's major industries who will press for a large share of the work, even to the extent of pushing the local product when it is inferior and more expensive.

The Tenderers are faced with a nasty problem. Within the consortia there are companies who would like to sell ironmongery as well as know-how; there is the problem of adequate return for them when their designs are to be built by others. We have seen some of the less happy examples of Ruritanian engineering and they are not up to nuclear power standards; but the Tenderer who insists on supplying his own equipment does so in the knowledge that local participation will be an important factor affecting the selection. The purchaser also takes risks if he insists too hard that local products shall be used; he cannot expect the main contractor to take responsibility for workmanship or delivery times of a sub-contractor thrust on him against his will.

In the event, little can be done except for the Purchaser to state his preference for local manufacture, other things being equal, if he wishes to secure a good contract with firm guarantees.

Fully guaranteed

The word 'Guarantee' covers a multitude of misconceptions and it is worth examining what contractual guarantees a Purchaser may expect and what value these are to him. One that he certainly will not get is a guaranteed quantity of electricity a year.

Capital cost The contract is for a specified plant at a fixed price. The only extras which can be charged are for specific items at the option of the Purchaser which are all listed and priced in the contract. In addition, there is usually an escalation clause to be included. This adjusts the contract price (up or down) according to an agreed formula if the cost of labour and materials varies between the time of signing the contract and its completion. It is a better risk for the Purchaser to accept this clause than to call for a guaranteed price, as the Tenderers are bound to be liberal in

covering themselves against losses.

What about design changes during the construction of the plant? It is no small problem with a project as novel as a nuclear station. Supposing the Contractor states that new experimental data indicates that he will need twice as many control rods? The nuclear consultants examine the evidence and conclude that the reactor will indeed be unsafe unless the new equipment (costing half a million pounds) is fitted. Who pays?

This situation has already arisen. There have been changes made to the design of the cores of the CEGB reactors during the construction period. An important change in the core design of the Garigliano BWR sold in Italy has been proposed following experience with zirconium fabrication.

In the case of the British reactors, some agreement must have been reached about the cost of these changes because the Generating Boards say that contract prices have been increased, while the manufacturers say they have been losing money.

So what is the foreign purchaser entitled to expect? Under a collaborative agreement to develop a new reactor type then both sides must expect to share the risk; but if a clear contract for a plant of such a size at such a price is signed, the Purchaser is not going to listen sympathetically to a request for extra costs. However, although his attitude is quite legitimate, the Purchaser may find himself faced with a serious dilemma. Nuclear safety cannot be exactly defined. The manufacturer may say that his tender specified a given number of control rods and this is the number he is going to provide even though it is now possible that the reactor will be unsafe.

Such dilemmas are inherent in constructing new types of plant and are one more reason for a cautious approach being made by prospective purchasers to nuclear power at the present time.

Time of construction The interest on the capital expended during the construction of a large project runs into millions of pounds. When all equipment has been erected, the Contractor will have received about 80% of the total contract price and every day that passes thereafter, costs the Purchaser thousands of pounds until saleable electricity is being produced. Therefore, a purchaser requires a Contractor to guarantee the day on which the station will begin to operate and to agree to pay a penalty for delays.

The Contractor is entitled to plead that delays due to certain causes are beyond his control. Act of God, War, Civil Commotion etc. are acceptable causes. Strikes may not be; bad management can contribute to bad labour relations. Late delivery of equipment is only an excuse if it is beyond the main contractor's control; so it is desirable for him to take responsibility for his subcontractors.

Station output There are many interesting aspects of this guarantee, particularly in view of the reactivity changes which take place in a running reactor. However, none of them is peculiar to stations sold abroad.

Radiation and effluent At the present time there are no universally accepted limits for radiation and the emission of gaseous and liquid effluent, although most countries base their regulations on the ICRP recommendations.

The Tenderer will be told the Purchaser's national standards and the limits should be guaranteed. It can be an expensive business to add shielding, filters, scrubbers, ion exchange plants and so on at a later date.

Workmanship The usual guarantee of free replacement of defective equipment which manifests itself during the first year of operation can be obtained without difficulty. However, a nuclear reactor may not be working on its equilibrium fuel cycle for some years after commissioning and defects which arise at that time are outside the normal maintenance limits.

Fuel burn-up The most important guarantee of all is that of fuel life, as it is on this that nuclear power economy entirely depends. No commercial aspect of a tender is more closely examined.

A fuel guarantee cannot mean that fuel elements which fail before their design lifetime are replaced free of charge. From the supplier's point of view, the guarantee must not be so generous that there is an incentive for the operator to take fuel out before its time, in order to claim a refund on it. On the other hand, the purchaser is faced with the fact that no commercially produced fuel has yet been proved in practice anywhere in the world. He must know what is to be his share of the gamble.

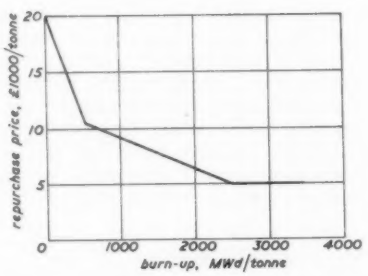


Fig. 1 Variation in repurchase price of spent fuel elements with burnup (Ref: Paper by Prof. Dr O. Lobl, OEEC Conference, Stresa, 1959)

The British fuel element guarantee is in the form of a curve which varies the buy-back value of the spent fuel according to its performance. If the fuel reaches its design lifetime or a little less it will be repurchased (for its plutonium content) at a basic price. At the other extreme, if it fails very shortly after entering a reactor it will be credited at close to its new price (in other words, replaced). Fig. 1 shows the curve of proposals said to have been made to Germany some time ago; it is not necessarily valid today. The steep part at the beginning is presumably based on the argument that at very low burn-ups, failures are most likely to be due to manufacturing defects.

A purchaser must pay, in addition, all costs of handling the defective fuel and shipping it back to the supplier. A glance at Fig. 1 will show that if the operator obtains only, say, half the output expected from the fuel, he will by no means be compensated for the loss of generation.

Unobtainable guarantees

The purchaser cannot obtain a guarantee for the number of kilowatt hours generated in a year. Although all nuclear power cost calculations are based on an assumed load factor (say around 75%), the attainment of this figure is the purchaser's own affair. This is legitimate because operation methods play a large part. Nuclear reactors have special availability problems. Their safety trip circuits hang by a thread; vital instruments 'fail to safety'; but safety can mean a shutdown and restarting may take half a day. There is much novel equipment which does not have a long background of development experience. Maintenance and inspection cannot be rushed because of the health hazard.

A shut-down nuclear station is an expensive liability; much more so than a conventional one because of its higher capital cost.

Conclusions (temporary)

With all these problems and reservations on his mind, Dr Schmoll is well aware that a certain degree of courage and determination is required to carry his project through. He believes in it, because he believes in the long-term value of the investment required. His contemporaries in other countries prefer to sit and watch for the time being. They will probably continue to do so until more of the world's large power reactors are successfully commissioned.

Harwell's spent fuel ponds

High energy gamma sources from Dido and Pluto spent fuel elements are being used for large-scale irradiation experiments and industrial applications

RADIOACTIVITY DECAY from the Dido and Pluto spent fuel elements is being used as a high energy gamma source for experimental and industrial applications. With an expected maximum activity of 2 million curies, this facility has an interesting potential for such uses as the sterilization of surgical appliances, soils and foodstuffs; the polymerization of rubber and for raising the melting point of polythene. It is being currently used for performance evaluation of lubricating oils and greases subject to certain nuclear conditions. (See *Progress in Industry*, page 111).

Before being transferred to the irradiation ponds, the fuel remains in the reactor for 12 hours after shut-down to allow certain high energy fission fragments to decay, after which it is stored for at least a day for cooling. The useful life of the spent fuel elements is about 100 days, during which the gamma activity declines from the original 60,000 curies per element to 2,000 curies. At this stage they are discarded and despatched to the reprocessing plant.

Functionally, the installation consists of two tanks sunk for the whole of their depth, the surrounding earth acting not only as a side shield but also as a retainer against water pressure. The fuel element reception and cropping pond is 12 ft long × 15 ft wide × 18 ft deep and is adjacent to the handling and irradiation pond which is 27 ft long × 15 ft wide × 20 ft deep. Both tanks are constructed from 10 swg stainless steel, with $\frac{5}{16}$ in. stainless steel bottom plates.

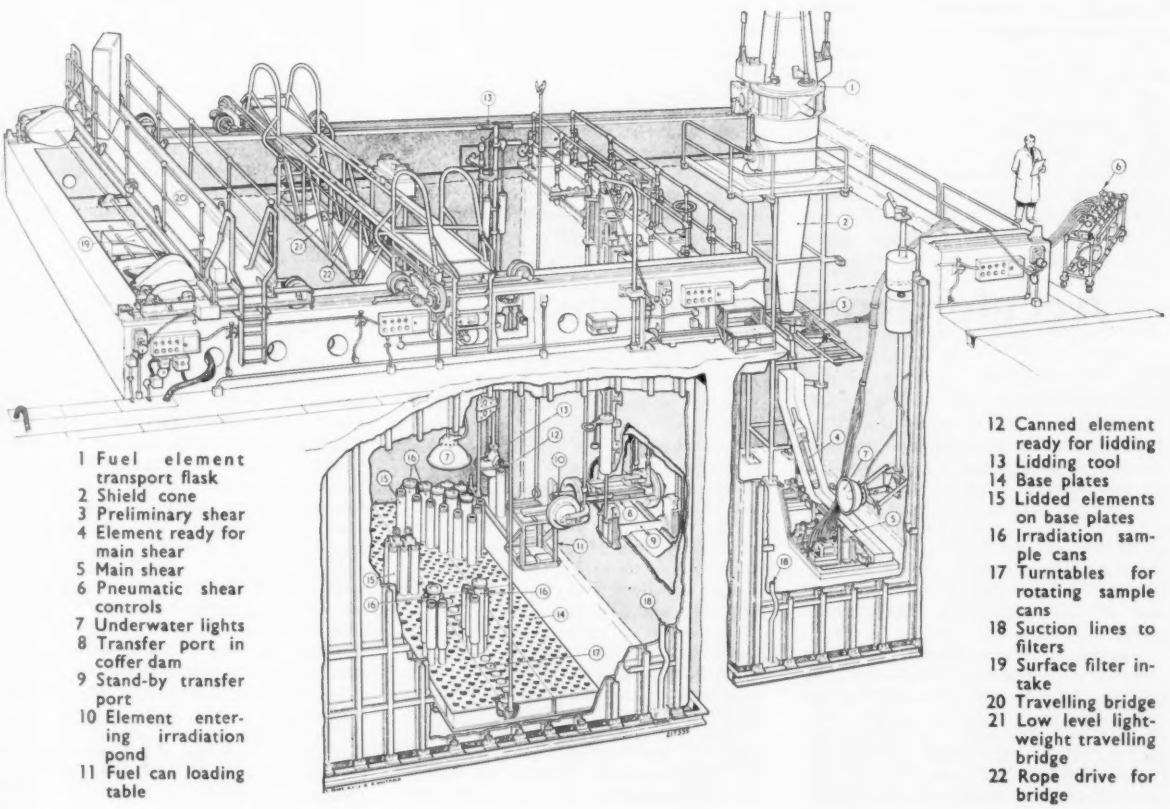
The shielding medium used is demineralized water to a depth of 20 ft, sufficient to give both density and distance shielding to reduce the dose rate at the water surface less than 2 c.p.s. above background from an end-window G.M. counter. The 70,000 gallons of water used to fill the two ponds gives a protection equivalent to $8\frac{1}{2}$ ft of concrete of 150 lb density, or 21 in. of lead.

After shearing, the element is passed to the transfer port mechanism, and enters the handling pond where it is lifted for canning. The fuel element cans are tubes of sandwich construction consisting of inner and outer skins of 16 swg 99% purity aluminium containing an intermediate layer of 14 swg cadmium to absorb emitted neutrons. The fuel elements are then located on a bedplate in accurate geometric formations.

Materials requiring irradiation are contained in sample cans and these are positioned on a rotating section of the bedplate. By this means, radiation doses can be uniformly distributed. Because of the high level of activity, component materials for use were very limited. Special carbon graphite has been used instead of p.t.f.e. or nylon. Because of corrosion, copper and duralumin were also precluded, with high purity aluminium used instead, where applicable. Considerable quantities of 18/8/1 stainless steel have been included, together with an S.80 type as a mating material, where galling action, or 'pick-up', had to be avoided.

Mechanical handling of sample cans was introduced to keep pace with the demand for irradiation space.

(For a full account of the design and engineering problems see report AERE-R3391 obtainable from HMSO at 7s)



1 Fuel element transport flask
2 Shield cone
3 Preliminary shear
4 Element ready for main shear
5 Main shear
6 Pneumatic shear controls
7 Underwater lights
8 Transfer port in coffer dam
9 Stand-by transfer port
10 Element entering irradiation pond
11 Fuel can loading table
12 Canned element ready for lidding
13 Lidding tool
14 Base plates
15 Lidded elements on base plates
16 Irradiation sample cans
17 Turntables for rotating sample cans
18 Suction lines to filters
19 Surface filter intake
20 Travelling bridge
21 Low level lightweight travelling bridge
22 Rope drive for bridge

Interkama Exhibition

Nearly forty British firms exhibited instruments and control equipment at Düsseldorf

FOUR HUNDRED and twenty manufacturers from 15 different countries participated in the recent 2nd Interkama, International Congress and Exhibition for Instrumentation and Automation, organized by NOWEA, Nordwestdeutsche Ausstellungs GmbH, in Düsseldorf. That there was a preponderance of German firms, was to be expected. Nevertheless, France, Great Britain and Switzerland were well represented. Apart from the ordinary exhibition of equipment covering measuring and control, test data evaluation, thermal techniques and power supply, distribution and application, there were practical demonstrations of some 200 instruments.

The Congress itself presented a complete survey of the state of the art and the trends in the development of techniques for measuring and control. The subjects discussed were independent, however, of the products of individual manufacturers and was not restricted to special fields of application.

The 38 British firms present at Interkama exhibited a large range of interesting equipment. Among the various signal generators of Advance Components, the most outstanding was the v.l.f. function generator, SG88, that provides any waveform at repetition rates down to one cycle every 200 seconds. Armstrong Whitworth's equipment included digital control techniques, strain gauges for accurate measurement up to 750°C and flowmeters for flows as low as 0·9 in/s and up to 30 gal/min. Examples of Blackburn data handling equipment included the BIE 2814 digital recorder, with a capacity of 50 channels and instrumentation for temperature control at the Trawsfynydd nuclear power station. In addition to the Anatrol computer, de Havilland had an electronic flowmeter, the Pottermeter, suitable for any liquid and pipline size. Bruce Peebles included their electronic leak detector which, although primarily designed for fluids under pressure, can in certain circumstances detect gas leaks.

An important development shown by Cambridge was a multi-point boiler feedwater analyser suitable for high pressure and high temperature boiler systems. The most interesting exhibits from Cossors were the 1076 oscilloscope with a maximum bandwith d.c. to 60 Mc/s at 50 in.V/cm, and the double beam unit, 1091.

Dawe's stand included the 443 single sweep and the 421 transistorized oscillators, a portable balancing instrument, a compact sound level meter, the 1400E, an A. F. analyser for measuring the components of complex electrical waveforms in the range 25–8000 c/s, and a fully transistorized frequency meter for frequencies between 10 c/s and 30 kc/s. The latest nucleonic equipment from Ekco, included an effluent monitor, type N657, a thermocouple trip amplifier for temperatures up to 600°C, and the Dynatron single-channel scanning pulse analyser.

Of interest among Electro Methods' components were the miniature chart recorder and Ether's 'Xactrol' potentiometer recording controller for operation at −200°C up to 2000°C. Farnell's stand included stabilized transistorized power supply units in the range 1 volt to 65 volts, 1–5 amps. Firth Cleveland demonstrated a new stainless steel vibration probe for level detection and an electronic tank contents gauge that measures to within 1/64 in.

A personal radiation monitor, and equipment for sampling radioactive dust, was shown by Flemings in addition to a variety of pulse generators, in particular, a crystal controlled type and a model for fast rising pulse inputs. Floor probes and radiation monitors were also well covered by General Radiological, who featured, in particular, a very highly sensitive scintillation monitor, NE148A and a portable fast neutron monitor, NE046, for the energy range 0·15 to 15 MeV. Two of the Graph Instruments' oscilloscopes, the 310 and the 350, are portable and suitable for general purpose use.

Hilger & Watts featured their Ultrascan, a fast double-beam recording spectrophotometer for routine analysis in the range 200–750 mμ. Hunt and Mitton's exhibits included diaphragm operated process control valves ranging from an orifice of $\frac{1}{16}$ in. to bores of 14 in. diameter. Labgear's display was representative of a wide range of nucleonic equipment and included the combined counter D4122 and gas flow counter D4126 to demonstrate 4 G.M. counting of low energy isotopes. Of particular interest on Marconi's stand was the TF1066A f.m. signal generator that covers 10–470 Mc/s, and can also provide amplitude-modulated outputs.

Other exhibits included Southern Instruments' multi-channel oscillograph recording system; Telequipment's portable measuring oscilloscopes; Muirhead's R.M.S. decade voltmeter, and analysers for transfer function and wave and frequency; Racal's data handling accessories; and Mervyn's high-speed pulse amplifier and large area scintillation counter. Suited to super-heated steam application, was Evans Electroselenium's recording flame photometer for continuous monitoring of sodium level.

Accelerator Conference

Fundamentals, research, and applications discussed at Amsterdam

THE SECOND International Particle Accelerator Conference, organized by the High Voltage Engineering Corporation, was held in Amsterdam from October 4–6. Twenty-two scientific lectures were presented by physicists and physical chemists of international repute, specialists in the experimental and practical uses of radiation energy from electronuclear machines.

Scientists participating in the programme represented universities in Utrecht, Saskatchewan, Copenhagen, Zurich, California, Erlangen, Uppsala, Amsterdam and Stanford; the Weizmann Institute, Israel, and other institutes in Germany, Italy and France; the research establishments of Saclay, CERN, Chalk River, Aldermaston, and the Medical Research Council; and the industrial companies, B.X. Plastics and Tube Investments.

The conference attracted over 300 participants from 24 countries and it provided the occasion for a useful interchange of ideas and techniques from both users and designers.

The session on nuclear physics covered papers on resonance reactions, positron distribution and annihilation, coulomb excitation, ultra-fast pulse techniques, and nuclear lifetimes, and concluded with a discussion on colliding beam techniques. In the field of particle research, the subjects covered included the design and experimentation with tandem electrostatic accelerators, polarized ion sources, millimicrosecond pulsing and a survey of recent advances in high-power microwave electron accelerators for physics research.

The final day was devoted to the discussion of techniques in physics, radiation research and industrial application. Physics papers covered high intensity neutron research, reactor physics with pulsed neutron sources, accelerator injectors and isotope separation. Topics concerning the research field included the use of electron bombardment in solid-state investigations, photoactivation and photoneutron activation analyses, the use of high energy radiation in biochemistry and microbiology, the development and the future of industrial process applications, and the application of the Van de Graaff generator to medical research.

The proceedings of the Accelerator Conference will be published in due course by the North-Holland Publishing Company of Amsterdam.

' The impression remains that . . . the USA is paramount, and that the UK is barely in the same business '

IAEA Conference on Small and Medium Power Reactors

by A. E. POWELL, B.Sc., M.I.C.E., M.I.Mech.E. (Partner in charge of nuclear work) and T. C. LEADER, B.A., A.M.I.Mech.E., Merz and McLellan

IT IS FASHIONABLE, at present, to question the value of conferences as achieving little that cannot equally well be managed by a study of published literature; but one merit of modern conferences on nuclear reactors, in contrast to those of the early days, is a tendency to deal unkindly with illusions. It was, for example, easy enough before this meeting to imagine that although the UKAEA's policy was to ignore the development of small and medium sized reactors, private initiative by firms interested in the field would keep the UK at least within striking distance of the Americans. After the conference no such impression was possible, and it is clear that some such reactors will have to be built in the UK if the disparity with the USA is not to increase and we are not to be left behind by Western Germany. This is not to say that there is a market for such reactors now, for the overall conclusion drawn from this conference is that only in very rare applications are they competitive today and that their future for the next ten years or so is still uncertain.

While it would be ingenuous to expect the number of papers presented by any particular nation to bear any but a very vague relationship to the effort applied there, the abiding impression remains that when it comes to small and medium power reactors the USA is paramount, and that the UK is barely in the same business. It is true that many of the papers at the Vienna conference were of a speculative nature, and while there is no stigma attached to pure thought and speculation, prospective customers are likely to be impressed most by those vendors whose speculations are amply reinforced by concrete experience. It was the United States alone among the major nuclear powers whose contributions revealed this completeness. It is known that the attitude of the UKAEA towards small reactors is based upon a belief that there is no prospective market for them within the next decade or so, but each appearance of the UK's representatives at a conference of this sort, holding the meagre hand dealt out by the AEA, is one step nearer converting this belief into reality for the UK.

General review of reactor systems

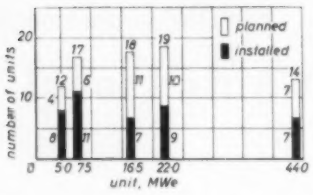
The development programme in the USA was quite fully described in papers in the first three sessions. In the first technical paper of the Conference (*1*) U. M. Staebler of the USAEC was at pains to emphasize that the direction of research and development work to date was to a better understanding of reactor technology. With opinion in the USAEC favouring the erection of relatively small experimental reactors and prototypes, there was, in fact, a considerable body of operating experience directly applicable to small plants.

The conference on small and medium power reactors organized by the International Atomic Energy Agency and held in the Wiener Stadthalle at Vienna in September was the first major international conference since that held in 1958 at Geneva. It was also the largest conference yet sponsored by the IAEA—indeed Mr Sterling Cole referred to it ' as their first major conference '—and was attended by some 260 delegates from forty countries. In all 63 papers were presented (half a dozen or so by title only), including 28 from the USA, 10 from the UK and four each from France and Western Germany. One interesting feature was that although there were delegates from Afghanistan and the Holy See, there was no representative from India.

The history of the USAEC Small Power Plant Programme was dealt with by D. F. Cope (*2*). In developing plans for the most recent plant in the series, the small pressurized water reactor, the AEC conducted a study to assist in the determination of its appropriate size, type and general characteristics. A questionnaire survey of public utilities was made, searching for evidence of recent or planned conventional plant of capacity between 5 and 44 MW, and of replies received from 186 utilities it was found that 58 had built conventional plant in this range within the previous five years, and 82 planned to start construction within the next two years. Figure 1 gives details of the replies received.

The USAEC superheating programme, whose history demonstrates the speed at which ideas in the US get translated into firm projects, was covered by Pursel (*3*), and J. K. Bratton gave an entertaining account of the US Army nuclear power programme (*4*). The economics of the Army reactors are perhaps the most favourable of any small reactors, since, as Mr Bratton said, their sites are in truly underdeveloped areas—indeed in places there exists practically nothing at all except the reactors.

The main protagonists of the boiling-water and pressurized-water approach, General Electric and Westinghouse respectively, each described their efforts in this direction. R. G. Lorraine of GE (*5*) attacked costs by aiming at more homogeneous nuclear and thermal core design for higher power density. This can be done by simplifying the core structure and arrangement of vessel internals, by effecting steam separation entirely within the pressure vessel, by improvements in instrumentation and by having a more compact and efficient arrangement of auxiliary and service systems. His subject was a natural circulation boiling water reactor. J. H. Wright of Westinghouse (*6*) had, in



Conventional plant unit size most frequently installed compared to the number installed in the past five years and those planned for the next two years (Fig. 1)

the main, similar objectives although he laid more stress upon evolutionary rather than design changes as the manufacturers and processers became more familiar with the technology. Two points of interest were his suggestion that ultimately more use would probably be made of carbon steel in the primary system, and that flux control might most economically be achieved by what he termed 'chemical shim' control—i.e. by altering the nuclear properties of the moderator by means of additives. In discussion, no doubt stimulated by recent reports of changes in the cladding material of the SENN reactor, Lorraine was asked to comment on the present status of zircaloy in BWR's. His reply was that faults in zircaloy in reactor conditions were found to spread more rapidly than faults in stainless steel, but that GE still believed in zircaloy and was carrying on with an experimental programme.

In their attempts to reduce the cost of energy from pressurized water reactors, the attention of Babcock and Wilcox in the USA was directed to improving neutron economy and power distribution in the reactor core and, as a result, the idea of the Spectral Shift Control reactor was born. This concept, brilliantly described and discussed by M. C. Edlund (*7*), depends upon modifying the neutron spectrum by admixtures of heavy water to the light water moderator so that resonance absorption in fertile material effectively achieves the control of the reactor normally performed by neutron-absorbing control-rods. In its more conventional aspects, however, heavy water received scant attention from US contributors, as—surprisingly—did organic moderated systems, upon which only one paper was read, describing the present state of the technology (*8*). Gas-cooled reactors of General Atomics design were, however, the subject of two papers. The second (*9*) was an enthusiastic presentation by F. de Hoffman, President of General Atomics, whose aim was to treat nuclear fuel similarly to conventional by 'burning' as much of it as possible and discarding the remainder. As an expression of this aim, he saw no difficulty in ultimately achieving up to two fissions per initial fissile atom by the use of the HTGR system, and claimed that up to 60,000 MWd/t had been reached by the fuel without any sign of deterioration.

It is understandable that the UK should not have had the same wealth of material to offer, but even so it was disappointing that in the 'General Review' sessions there should only have been three UK papers. No doubt the preoccupation of many of the UK manufacturers with their marine reactor tenders had some bearing on this, but the fact is that the previously declared interest in small and medium power reactors by certain British groups was not advertised at this conference, nor was any exposition offered of the UKAEA attitude.

M. C. Hartnell-Beavis (*10*) described the studies by GEC of small land-based gas-cooled power reactors and provided interesting and valuable details of the optimization studies performed. The designs he described were based on the cross-flow fuel element developed by GEC, which differs markedly from the rod-type element proposed for the Windscale AGR, and the optimum mean fuel rating found in these studies was between 20 and 30 MWd/t—at least a factor of three higher than the rating proposed for the AGR. At present the canning material proposed by GEC is stainless steel, but eventually a change is foreseen to impermeable graphite canning with an estimated 30% reduction in fuel running costs. Figure 2 shows the variation of fuel enrichment with maximum fuel rating, canning material and can thickness, and the advantages of graphite do not require underlining.

CONFERENCE BUSINESS

- 4 sessions on a general review of reactor systems
- 2 sessions on operation, construction, fuel cycles and staffing
- 2 sessions on economics
- 1 session on international co-operation and the role of small and medium power reactors in meeting energy problems

At the end of the presentation of his paper, Hartnell-Beavis aired a subject which is clearly of some concern to UK manufacturers—that of the supply of enriched fuel — by asking the USAEC and the Secretariat of the IAEA to comment on the availability of enriched fuel from the USA and the USSR. In reply, Prof. Laboulaye for the Secretariat suggested that interested parties should address their specific enquiries informally to the IAEA, who would then be able to give a considered opinion.

A strikingly different approach to economy in small gas-cooled graphite moderated reactors was proposed by R. E. Strickland (*11*) who avoided the problem of enriched fuel, offering a natural uranium low pressure design. It was argued that such a reactor was limited by criticality considerations to a certain minimum core size and that, therefore, capital cost economies in remote areas could best be achieved by light scantlings in the primary circuit and by a compact layout. Moderate fuel ratings and temperatures permitted simple protective gear to be used and allowed the station more easily to follow system load changes, and simple off-load charge/discharge equipment, with long fuel dwell-time at low load factors, reduced operating costs. One of the consequences of the low gas pressure chosen (60 lb/in²g) is to necessitate circulators of proportionately higher capability than is usual in magnox reactor designs, and the gross and net electrical capabilities of the station are 30 and 24·5 MWe respectively. Table I gives details of the capital cost estimate, which at £168/kW is little more than the expected ultimate cost of Bradwell. Running, as it did, contrary to general thought in gas-cooled reactor technology, this paper excited some disbelief, particularly, in discussion, from J. Bussac of France who had earlier described French developments in gas cooling. The remaining UK paper in this section (*12*) was an account of an attack by Babcock and Wilcox upon capital costs of nuclear stations by pure design, in which the steam generators were made integral with the reactor.

The Federal Republic of Germany was ably represented in the 'General Review' section by three papers, of which the first (*13*) was an account of the 15 MWe boiling water reactor of GE design being erected at Kahl/Main. This reactor is being built under the same conditions of contract as are normally applied to conventional plant in Germany, but it is clear that AEG were surprised by the legal and administrative difficulties encountered on the way. The imaginative approach of the BBC-Krupp reactor to high specific output in a gas-cooled system was described by A. Setzwein (*14*).

Canadians, in two papers, contrived once more to be impressive both for their confidence in their own heavy water route and for the remarkably low fuel costs which they forecast. The contrast between Canadian confidence and US reluctance in heavy

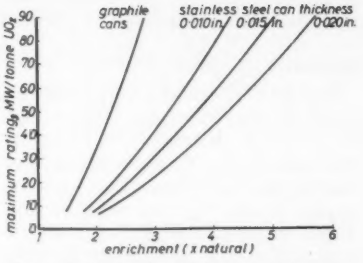
water technology drew some comment during discussions, for which the US explanation lay apparently in the relative states of development in the two countries. The unique contribution by France, to this section, comprised an account by J. Bussac (*15*) of the French gas-cooled programme and its application to medium power reactors. As has been mentioned, Bussac and Strickland (*11*) were at variance, with Bussac believing there to be no future in graphite-moderated reactors using natural uranium below a power of 60 MWe. It seems that a similar view is held by at least one concern in the UK.

The natural circulation boiling water reactor appears to have found favour also in Japan, and the only design mentioned at the conference which did not derive from the USA was for a 90 MWe version proposed by Hitachi Ltd (*16*). Like the improved BWR described by Lorraine (*5*), all steam separation takes place internally to the pressure vessel.

Construction and operation

The highlights of the fifth session of the conference, which was devoted to experience in construction and operation, again appeared in US papers. Contributions by D. L. McDaniel (*17*) and D. J. Roy (*18*) painted a reassuring picture of activity and contamination levels within the primary circuits of boiling water reactors, even after having operated with intentionally defective fuel elements, and demonstrated that even quite drastic alterations were possible to the vessel itself without undue complication. J. G. Gallagher in a third paper (*19*) offered a mass of information for designers, based on three years' operation of Alco's SM-1 reactor.

Apart from a Russian paper inserted at the last minute and dealing with operation of, and superheating rigs in, the first nuclear station in the USSR, the remainder of the session was devoted entirely to UK papers, and while the operation and construction of Calder-type reactors is still of considerable interest in the UK itself, and



The variation of enrichment with max. rating, canning material and can thickness (Fig. 2)

probably to large reactor enthusiasts elsewhere, the accounts of them suffered at this particular conference by having been taken out of context. The record of four years' operating experience at Calder is nevertheless impressive, and the paper (*20*) by T. Tuohy contained certain information which had not hitherto been generally released. The irradiation of magnox-metal fuel elements attracts considerable attention in nuclear circles, and it was stated during the discussion that the maximum irradiation of fuel elements in Calder so far was 2600 MWd/t, with a hundred fuel elements having passed the 2000 MWd/t mark. The construction site at Chapelcross (*21*) presented a scene of activity hitherto unparalleled in nuclear work, with work on four reactors proceeding virtually simultaneously to meet the tight schedule. It deserved mention as an achievement, but its value for the future is limited since it is unlikely that such a performance will ever be called for again.

Safety and staffing

In the parts of Section VI dealing with safety and staffiing, considerable interest was shown at the discussions on licensing and staffing. M. B. Biles (*22*), when asked how the USAEC determined at what point the safe lifetime of a reactor was reached, had to admit that this problem was not yet resolved. This is of some interest in view of a recent report that Dresden had applied for a 40-year operating licence. Some surprise was evident that, in contrast with US practice, no operating licence was issued by the Calder reactor school, nor was attendance obligatory before becoming a reactor operator in the UK. The size of the staff at Calder had come under fire on the previous day, during the discussion on paper SMPR/2, and overstaffing in the UK was further attacked by R. F. W. Guard (*23*). Even Guard's conservative figure (by UK standards) of about one man per MW was made to look extravagant by comparison with some quoted in US papers, and the difference generally seems to be accounted for by maintenance staff. In the US Army projects, which are obviously special cases, the staff needs are less than one man per MW even in 20 MW sizes, but each man is not only a trained operator but also a specialist in the maintenance of one particular aspect. In the same session, an interesting paper by E. Jantsch (*24*) described safety features of underground installation, which was said to be the only answer for reactors sited in Switzerland. Jantsch estimated the cost of the underground installation as only 10% more than conventional containment.

Fuel cycles

One French paper and two from the USA were devoted to fuel cycles, of which one (*25*) by J. W. Ullman presented a summary of the factors involved in the nuclear fuel cycle, which should constitute first class material for anyone concerned in an attack on high fuel costs. An account (*26*) of the Plutonium Recycle Project at Hanford included interesting new material on fuel fabrication, in particular on cold-swaging of UO_2 fuel elements canned in zircaloy and on a process involving high intensity vibrational compaction which is of particular application for plutonium-bearing fuels.

Economics

The two sessions on cost evaluation and economics were an interesting compound of realism and speculation. Both F. W. McCloska (*27*) and J. F. Kaufmann (*28*) were careful to point out that in making cost comparisons the site conditions, design philosophy and completeness of all charges affected the comparison materially, and it was therefore important that the ground rules should be carefully defined before making such comparisons. McCloska concluded that nuclear plants as built today were at least 50% more costly than similar sized conventional plants, and that even by 1968 this disparity would only have fallen to 30%. The task of making nuclear plants competitive therefore

TABLE 1 *Capital cost estimate*

	£	£	$
Civil engineering work		750,000	(2,100,000)
Primary plant and equipment			
Core	600,000		
Reactor vessel	260,000		
Boilers	290,000		
Gas circulators and drives	250,000		
Other plant and equipment	600,000		
		2,000,000	(5,600,000)
Secondary plant			
Turboalternator set and ancillaries	350,000		
Other secondary plant	250,000		
		600,000	(1,700,000)
Electrical equipment		250,000	(700,000)
Engineering and contingencies		500,000	(1,400,000)
TOTAL CAPITAL COST		4,100,000	(11,500,000)
Cost per kW of output capacity		168	(470)

depended crucially upon attaining overall fuel costs appreciably lower than conventional fuel costs. He indicated the regions in which capital cost reductions could most easily be made. H. S. Prosser (*29*) of Humphreys and Glasgow was somewhat more optimistic than McCloska in believing that the capital cost of PWR plants might fall by as much as 40% in 7 to 10 years, and he also showed lower capital costs than those mentioned by US contributors—based, apparently, on lower manufacturing costs prevalent in the UK. Where McCloska had chiefly examined capital cost reductions, J. Lane (*30*) speculated upon fuel cycle cost improvements consequent on improvements in technology.

The attitude of the generating utility towards the economics of nuclear power was shown by Prof. Lévai of Hungary (*31*) who called attention to a fact which is seldom appreciated by those of purely nuclear background, namely that the load factor allocated to a given station in an interconnected system depends only upon its running costs and not upon the capital invested in it. The only correct way to determine the feasibility of a nuclear station was to analyse the effect of its introduction upon the whole system. Another paper of interest to operators was that of E. Jones (*32*), who described how the Consumers Public Power District in Nebraska have arranged to integrate the Hallam plant into their system with the minimum of disturbance. Two papers also discussed the application of nuclear reactors for the process industry, and even here, in comparatively favourable conditions, no clear economic advantage was established.

The economists really came into their own in the final session when discussing on theoretical grounds the conditions for, and the effects of, the introduction of nuclear power principally into underdeveloped countries. Some of the effects discussed were major imponderables and probably of little concern to any but philosophers, but UNO produced a realistic survey of the power situation in less-developed countries (*33*) which emphasized the less well-known difficulties of power supply in such areas. The continent of Africa received comparatively optimistic treatment in two papers, in one of which (*34*) the high costs of transport and of transmission from hydro-electric stations in the Belgian Congo was said to favour the introduction of small nuclear stations in certain regions, but to determine whether or not the findings of this paper were of much practical value required a more detailed knowledge of the geography of the Congo than most delegates possessed.

International collaboration

The final technical paper read was a general account of the Dragon project by C. A. Rennie, with particular emphasis on its role as an example of international collaboration. Other examples of the high temperature gas-cooled reactor, the logical ultimate objective of the gas-cooled graphite moderated approach, were of course dealt with in the conference and have been referred to above. It is, however, interesting that the time scale for extrapolating such a system to power producing applications seems to be more protracted in the UK and its associates than for similar systems in either the USA or Western Germany.

Summary

A general review of the conference was made in the final session by Professor H. de Laboulaye, who had also been struck by the magnitude of the US effort although he commended the enterprise of other countries. He noted the tendency to optimize neutron economy throughout the irradiation life of the fuel and expressed his belief that this and the evolution of engineering from what he called 'the dinosaur age' would combine to reduce costs. Experience in construction and operation showed signs that equipment devoted to safety could be simplified, and he hinted at a possible IAEA committee to examine the problems of staffing. The theme of many papers had been that of cost reduction and it was his opinion that the prices quoted in this conference had been somewhat lower overall than those that had emerged at Geneva in 1958, demonstrating that the technology was on the right path.

A consistent thread running throughout the whole meeting had been the great interest shown by the Secretariat in the deliberations of the participants, and the IAEA are to be congratulated upon having sponsored a conference whose proceedings will undoubtedly prove of considerable value in furthering the progress of small and medium power technology.

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A well designed protection scheme insures against corrosion failures and leads to savings in materials. Cathodic protection is to be used in the AGR installation and for Winfrith's effluent pipes

Internal Cathodic Protection

by C. PLUMPTON, M.A., Ph.D., H. M. POWELL, B.Sc., M.I.E.E. and C. WILSON, B.Sc.

THE MAJORITY of metals, commonly used in engineering structures, are liable to suffer from corrosion. Since the rate of corrosion may strongly influence the useful life of an industrial plant, standard design practice tends to require high safety factors coupled with complicated design procedures which allow for relatively easy replacement of corroded components.

For our purposes metallic corrosion may be taken to be primarily associated with the flow of current in an electrolytic cell. The anodic areas, from which the current flows into adjacent electrolytes, are usually seats of rapid corrosion. The corresponding cathodic areas, into which the current flow from electrolytes, are not subject to corrosion. The existence of such anodic and cathodic areas is mainly due to the presence of galvanic cells but corrosion due to stray potentials, such as half-wave rectification of a.c. leakage, is not uncommon.

THE PRINCIPLE OF CATHODIC PROTECTION

A metallic surface may be protected against corrosion by ensuring that current from the surrounding electrolyte flows *into* every point of the surface. This method, known as *cathodic protection*, involves the installation of suitable anodes in the electrolyte. The surface requiring protection then becomes completely cathodic. Frequently a suitable combination of cathodic protection and the application of an insulating coating gives cheap and efficient protection.

In recent years cathodic protection installations have been fitted in numerous equipments employing sea water for cooling purposes. In particular the inner walls of steel pipelines carrying sea water have been protected most effectively. Further impressed current schemes have been installed, with varying degrees of success, in the end boxes of heat exchangers carrying the coolant in the tubes. Such applications will be of great interest to nuclear engineers.

Attempts have been made to protect the inner walls of a variety of rectangular tanks including those carrying 'flash over' water from steam condensers. It appears that such installations may not have been fully successful but new methods, stimulated by the theoretical analyses illustrated in this paper, have suggested reasons for such failures and point the way to techniques which may give rather more satisfactory results.

Cathodic protection engineering is primarily concerned with the materials, design and positioning of anodes, but until recently general internal cathodic protection was considered impractical because of the relatively large volume of the anodes. However, the use of new materials in anode design has now made internal protection of quite small structures by cathodic protection a practical possibility.

MATHEMATICAL THEORY

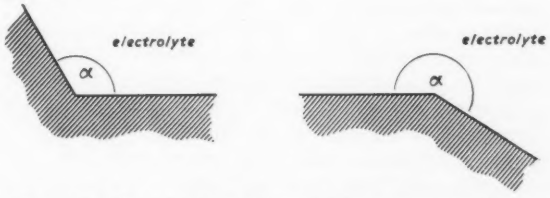
Basic equations

In a preliminary theoretical investigation we make assumptions that the electrolyte is of uniform conductivity σ and that the surfaces of anodes and cathodes are equipotentials with the cathodes earthed. The electric current j and the electric potential V satisfy the field equations

$$j = -\sigma \text{ grad } V \tag{1}$$

$$\left(\frac{\partial^2}{\partial x^2} + \frac{\partial^2}{\partial y^2} + \frac{\partial^2}{\partial z^2}\right) V = 0 \tag{2}$$

with surface boundary conditions $V =$ constant on the anode and $V = 0$ on the cathodes. Further if I is the current emitted by an anode, then the flux of j out of a surface enclosing this anode is I. Thus the theorems of general potential theory may be employed and the analogy with electrostatics leads to immediate derivation of some general theorems. The 're-entrant angle theorem' implies that, in the absence of a protective current, an edge between plane faces inclined at less than 180° will suffer little or no corrosion, whereas an edge between faces inclined at an angle exceeding 180° (Fig. 1) will be the seat of rapid corrosion. However, application of protective current will give immediate protection to the re-entrant edges since the current density entering such edges is theoretically infinite.



Corrosion effect on edges without cathodic protection (left) with the non re-entrant angle where faces are inclined at less than 180°, no corrosion is expected. (Right) with the re-entrant angle, where the angle is greater than 180°, there will be severe corrosion (Fig. 1)

Current distribution over a plane surface

The potential due to a small spherical anode, emitting total current I and embedded in an otherwise infinite medium of uniform conductivity σ, is $I/(4\pi\sigma r)$ where r is the distance from the anode centre. This is true provided r is large compared with the anode linear dimensions.

Applying the method of images, the potential at P due to an anode placed at a distance p from a semi-infinite

earthed plane is $Ip(r_1^{-1} - r_2^{-1})/4\pi\sigma$ where r_1, and r_2 are the distance of P from the anode and its optical image in the plane respectively. At distance x from the point of the plane nearest the anode, the density of protective current, j_n, entering the plane is $Ip/\{2\pi(p^2 + x^2)^{3/2}\}$. Thus

$$x^2 = \{Ip/(2\pi j_n)\}^{2/3} - p^2 \qquad (3)$$

Then elementary maximum-minimum theory indicates that, if the current infall for effective cathodic protection of the plane must not fall below $\triangle$, protection of the greatest possible area is a circle of radius $\{I/(\pi\triangle)\}^{1/2}/3^{3/4}$. This result may also be expressed by saying that to protect the area within a circle of radius c with the minimum protective current $\triangle$, the anode must be distant $c/\sqrt{2}$ from the wall and emit current $3^{3/2}\pi c^2\triangle$.

General scope

It is not possible to obtain a precise mathematical determination of the current flow produced by anodes placed in a vessel of arbitrary shape. However, simple and reasonably accurate solutions of many practical problems are relatively easy to obtain. Thus, for example, solutions have been derived (*1–5*) for anodes placed in pipelines and rectangular or cylindrical tanks with or without free liquid surfaces. The effect of an insulating coating may be determined also. An interesting and essential feature of the analysis is that it suggests the introduction of new anode designs and anode arrays. Thus the concept of line and annular anodes and arrays discussed elsewhere (*5*) may well have a substantial contribution to make in this field. In fact, provided that the mechanical problems involved in the manufacture and mounting of these arrays are overcome, it would appear that internal or external cathodic protection may be successfully applied to almost any type of engineering structure.

DESIGN TECHNIQUES

As indicated above, the introduction of anodes into the electrolyte is a fundamental necessity in cathodic protection schemes. The voltage which drives the current from the anodes to the cathodic walls may be derived in one of two ways. Either the anode is manufactured of material such that the natural voltage difference between the anode and cathode materials is sufficient to drive current of appropriate magnitude in the current sense, or an external d.c. voltage is applied between anode and cathode. The former method, known as the sacrificial anode method, employs such anode materials as magnesium, zinc and aluminium but is not subject to fine control as is the second or impressed current method in which typical anode materials are scrap steel and graphite. For internal cathodic protection work, the introduction of platinum and lead alloys as anode materials has resulted in the development of anodes capable of emitting high surface currents.

Although some of the conclusions implied by the mathematical analyses have not as yet been verified experimentally they suggest some features which may be of interest to the design engineer. Thus the introduction of re-entrant angle sharp edges should be avoided wherever possible. In considering the potentialities of cathodic protection from an engineering point of view, it is obviously necessary to balance the economies effected. The savings come under several headings. The first being in the initial design, since obviously lighter sections can be used, as an additional 'corrosion allowance' is not necessary. Such an allowance is in any event an illusory safeguard since it is based on the assumption that corrosion will be substantially uniform all over the surface involved, whereas in actual practice it is far more likely to be concentrated over comparatively small areas and of such a depth as to nullify the effect of the allowance. The second obvious source of loss is the leakage or pollution of the product contained in the vessel. Thirdly, there are the possible effects of leakage of substances which may be noxious, toxic or inflammable. There is also the direct expense of replacement and repairs and, lastly there is the question of the loss of use of the plant during repairs and replacements which may involve very large sums.

DESIGN PROBLEMS CLASSIFIED

The Rectangular Box Cathodic protection alone may not give a completely satisfactory solution in this case; a suitable combination of cathodic protection and insulating coatings appears to be most effective.

The Cylindrical Tank Cathodic protection is most suitable for such structures but complicated anode design may well make the method uneconomic for small containers.

The Long Tube Here again cathodic protection is suitable for tubes down to 8 inches in diameter but only when the cost of coatings is high.

The Open-ended Tube Many problems exist in which long tubes enter the structure requiring protection e.g. the conventional power station steam condenser box. Certain protection of the end boxes and the first diameter length of the tubes, the seat of the most severe corrosion, is achieved by cathodic protection.

Combinations of the above classes cover almost all structures used in modern process plant but, at present, some corrosion problems appear somewhat difficult to solve using cathodic protection.

The most obvious preventive steps can be taken at the design stage, the first of which is the selection of the metals used. It is all too easy, when selecting a certain metal for its corrosion resistant properties, to forget the possibility of its acting as a cathode to other parts of the structure. This seems too obvious to be overlooked but is nevertheless a frequent cause of trouble. A further step at the design stage can be taken on the assumption that cathodic protection will be used, that is avoidance of such forms of design as will prove difficult or impossible to cover. This implies the absence of narrow compartments or interstices into which protective current must be forced and also the fairing off of re-entrant corners. Metal edges protruding into the compartment add to the difficulties as they tend to 'rob' other parts of protective current.

Having designed the vessel with the above points in view, the application of protection must be studied and, from the principles suggested by theoretical analysis, it should be possible to arrive at a fairly accurate ideal positioning of the anodes. It is at this point, however, that practical consideration may render it necessary to depart from such ideals and accept the nearest practicable compromise. It is desirable with galvanic anodes to avoid 'channelling' of the majority of the protective current to nearby steelwork, such as the adjacent portion of the support member. The latter may therefore need to be

galvanized or covered with an insulating coating. With these considerations clearly understood, and a reasonably accurate idea of the total current required, it should be possible to design galvanic anodes of such superficial area and volumetric content as to give the required current for the designed life.

In the case of impressed current anodes, the design is rather different in as much as the supports have to constitute current carrying members in addition to supporting the anodes. They must therefore be insulated and must be brought through the walls of the vessel by insulating sleeves or glands. They have, however, the inherent advantage that a single anode can provide a very much larger output of current for its size and this current can moreover be controlled.

Mathematical analysis makes it clear that uniform spread of protective current is impossible; each anode tends to produce peaks of protective current on the adjacent cathodes. A major objective of any cathodic protection scheme is the reduction of these peaks to a minimum whilst ensuring that the resulting minimum current densities are adequate for full protection. This may only be achieved when the anode design is complicated or when a large number of small anodes are used. Thus really efficient cathodic protection may be uneconomical unless adequate provision for it is made in the plant design at the very outset.

The current density peaks may be expected to be greatest when the cathode is a flat surface. Making the surface concave will tend to reduce the peak of current (and consequently the total current) without impairing the efficiency of the anode array, whereas making the surface convex may result in stagnant water pockets where the convex surface edges meet the adjacent surfaces. This suggests that the use of dished plates, as opposed to flat plates, may reduce corrosion and will cut the cost of cathodic protection schemes. Thus it is now more or less clear that for cathodic protection, a curved steel plate is preferable to a flat one and that the easiest shape to protect from within is a sphere. A spherical shape is usually impracticable but a cylinder with concave inward ends may frequently be substituted for a rectangular tank with great increase in anti-corrosion efficiency.

FUTURE PROSPECTS

A feature of the work of the mechanical design engineer is the search for new metals and alloys which may prolong the life of plant installations. Such new materials are frequently very costly and are primarily needed because of the failure of the commoner metals to withstand corrosive conditions. But the incorporation of cathodic protection at the design stage may give considerable reduction in capital costs for any specified life requirements. Generally speaking the choice of metal thicknesses is based on operating conditions, but the introduction of large safety factors frequently implies the use of metal thicknesses far in excess of those actually required. A well designed cathodic protection scheme not only gives insurance against corrosion failures but enables safety factors to be reduced, and hence considerable savings in initial material and construction costs. Further, it is common for plant design to be complicated by the necessity for the replacement of corroded parts. Thus cover boxes, which may well be permanently sealed, must be constructed so that easy access is possible, whilst studding and bolting must be used in lieu of welding and extended casting. Periodic shut-down and inspection programmes have to be drawn up and carried out, thereby giving rise to expensive 'outage' time.

Clearly considerable savings in maintenance costs may be made when replacement of corroded parts is no longer necessary but, with the rapid development of engineering techniques since the war, plant may become outdated after a relatively short life and the economics of this replacement saving may be more apparent than real. The real savings of an efficient anti-corrosion system are frequently hidden and may be of prime importance in the reduction of the capital costs of many items in a plant.

The structures lending themselves to internal cathodic protection may be divided into three main sections, namely those transporting water, those cooled by water and those storing water. Water transportation is a field in which internal cathodic protection is already established. Inner walls of pipelines carrying sea water have already been successfully protected and experiments are in hand to determine if cathodic protection is economically applicable to pipelines carrying potable waters. The corrosion of sea water pumps is a constant source of trouble in refineries and generating stations using coastal water and the protection of these pumps would be welcomed.

Water cooling is a standard industrial practice and many plants are sited on the coast primarily for the reason that cooling water is available there in unlimited quantities. There exists a vast number of heat exchanger designs and already many of these are protected with cathodic protection schemes. Unfortunately the design of the heat exchanger is frequently the major factor in the rapid corrosion generally observed, since the units are usually massive galvanic cells. Some re-education of mechanical engineering designers, together with improvements in anode materials and current distribution techniques, could well imply that cathodic protection will eventually become standard for all water-cooled heat exchangers. The savings in materials alone would be very substantial since the elimination of 'corrosion allowances' drastically reduces wall thicknesses.

Water storage covers a wide and complicated field, ranging from the domestic water tank to vast storage tanks for stand-by coolant or fire fighting purposes. Cathodic protection has been applied successfully in domestic tanks, but it is doubtful whether such an application is worthwhile on economic grounds. In general, it would appear that the larger the storage tank, the greater the financial savings from the application of cathodic protection. As previously pointed out, rectangular tanks are difficult to protect but new techniques developed from theoretical investigations have suggested economical solutions still needing experimental verification. Cylindrical and spherical tanks, on the other hand, lend themselves relatively easily to cathodic protection.

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Both the conference and the concurrent exhibition showed good British participation

International Instruments and Measurements Conference and Exhibition

a report by Dr DENIS TAYLOR, Plessey Nucleonics Ltd

1. THE CONFERENCE

INCREASING EMPHASIS on reactor control was a feature of the Fifth—and most successful—International Instruments and Measurements Conference at Stockholm where the papers on nuclear science numbered 42 against a total of three at the second conference in 1949. Of the 1960 total, 26 came from the UK and it was on receipt of these that the organizers—the Royal Swedish Academy of Engineering Sciences and the Swedish Association of Technical Physicists—decided it was desirable to add a new section on 'Reactor Control' to the proceedings.

Nuclear instrumentation

The nuclear instrumentation session began with a survey (*1*) on semi-conductors given by Dr G. B. B. Chaplin including several semi-conductor devices for which no thermionic valve counterparts exist, and which offer interesting possibilities in nuclear instrument design. In this connection the Boff diode and its applications to fast coincidence circuits, the tunnel diode and its use in scalers and discriminators and particularly fast data-processing equipment, and the *pn* junction and its use as a detector of charged particles were all discussed.

A number of other papers presented described the use of transistors and other semi-conductor devices. Notable among them being two by E. Dissing-Sörensen (A.B. Atomenergi, Sweden) (*2,3*).

Health physics instrumentation

H. D. LeVine (USAEC, New York Operations Office) gave details of investigations to evaluate the radioactive content of the paints, flooring, metals, plastic, manufactured items, etc., used in the production of a counting system (*4*).

I. O. Andersson and I. Nilson (A.B. Atomenergi, Sweden) then described the human body counter they have designed. It comprises a large Na(Tl)I scintillator used in association with a 70-channel pulse-amplitude analyser.

G. D. Smith and D. A. Kelly (Plessey Nucleonics Limited) (*5*) reviewed the increasing use of semiconductor devices; the use of diffused silicon junctions as alpha-particle spectrometers; the wider use of gamma spectrometers in health monitors; the use of neutron activation techniques and advances in neutron monitoring.

They were followed by F. Humbel and A. Stebler (Landis and Gyr, Switzerland) who spoke about the measurement of radiation dose rates using halogen-quenched Geiger counter circuits while I. O. Andersson, J. Braun and B. Soderlund (A.B. Atomenergi, Sweden) described a Hand Monitor for the simultaneous measurement of alpha and beta activity. This detector employs four gas-flow proportional counters. The counter closest to the hand measures the alpha-activity. The beta-radiation mostly passes through this system and is registered on the outer counter as the voltage applied to the alpha-counter is 1000 V lower than that for the beta-counters. The beta-radiation, therefore, passes through the alpha-counter without producing pulses.

Scintillation techniques

The second day of the Nuclear Instrumentation Session began with a survey lecture by R. B. Owen (AERE, Harwell) on scintillation techniques (*6*). Scintillation counters have become one of the most widely applied forms of radiation detector since they can, with high efficiency and to a considerable degree of precision, provide information on the time of arrival, energy and nature of the detected incident particle, he said. Scintillation Track Imaging systems were becoming available which provided additional information on the position of particles. Mr Owen, in particular, discussed the limitations in accuracy with which any of these properties can be determined, and also where possible, methods by which the techniques might be improved.

S. Hellström (A.B. Atomenergi, Sweden) explained that a liquid scintillator applied for the measurement of radioactive assay presents 4π geometry when the material is homogeneously dissolved in it, and avoids problems due to self-absorption (*8*).

An interesting paper (*9*) which gave details of the factors governing the stability and resolution of a commercial type of gamma-ray spectrometer was presented by B. Bölger (N.V. Philips Gloeilampenfabrieken, Eindhoven). According to this account, after the warming up time, the drifts in the high voltage, channel width, amplifier gain and other electronics were negligible. The main source of instability was shown to be due to the photomultiplier. Photomultipliers of different manufacture using CsSb as the dynode material show the same behaviour as to fatigue effects. The gain of the multiplier depends on the intensity of the source to be measured and varies with time.

AT THE CONFERENCE

held in Stockholm this September there were five parallel sessions

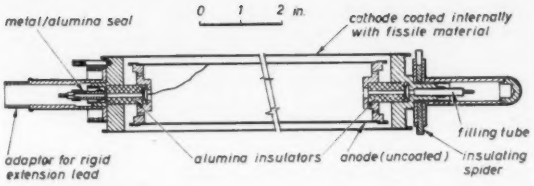
- Automatic process control
- Physical methods of chemical analysis
- Nuclear instrumentation
- Measurement of electric and magnetic quantities
- Nuclear reactor control

Isotope applications

R. K. Barnes and J. H. Barrett (DSIR, England) described a beta-particle absorption gauge for recording variations in the mass per unit length among materials in the form of threads (*11*). The thread under examination passes longitudinally along a slit positioned between the beta-particle source and the detector, both of which subtend a wide angle at the slit. The geometrical arrangement, including the positioning of the thread relative to the slit was chosen to minimize the critical dependence of the response upon the position of the thread. The range of thread covered was 50 to 300 dernier, i.e. about 5 to 30 $\mu g/cm^2$.

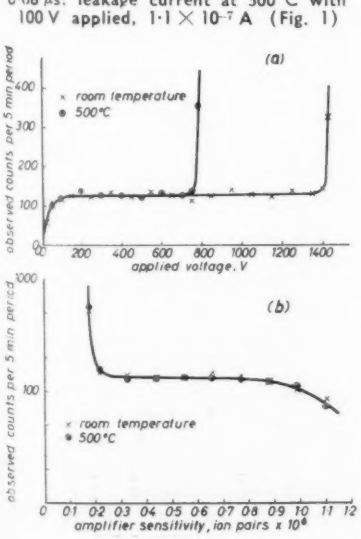
O. Fineman (Karlstads Mekaniska Werkstad, Sweden) also described two types of beta-meters used in pulp and paper research. One is built to measure the formation of the paper, i.e. the inhomogeneity when holding the paper towards the light. The instrument measures, in fact, the local weight per unit area in areas of approximately 0·4 mm^2. The other is of the more usual type and measures variations in the difference in weight per unit area that exists between two points in a pulp or paper machine. As the area-weight of the fibre remains the same as the paper moves along the machine, the difference depends upon the amount of removed water between the two points in the machine.

T. Westermark, B. Sjöstrand and H. G. Forsberg (Royal Institute of Technology, Stockholm) dealt with much the same subject (*12*). They considered the difference method, but with provision for special drying of the material between the two measuring points where the beta-gauges are installed. They described an experimental set-up using a Pm-147 radioactive source and discussed sensitivity in relation to moisture change, precision related to source strength, drying method (including power requirement) and dependence of drying rate on moisture content. They also discussed the possibility of in-line gauging in industrial applications.



Schematic diagram of the high temperature pulse-type fission chamber for reactor control (see ref. 14) (Fig. 2)

High temperature characteristics of the ¼ in. dia. pulse-type fission chamber with 12 ft extension lead described in the paper by Abson, et al., (a) saturation characteristics, (b) integral bias characteristics. The chamber is filled with purified argon at 30 lb/in²; fissile material U-235; amplifier time constants 0·08 μs; leakage current at 500°C with 100 V applied, 1·1 × 10⁻⁷ A (Fig. 1)



Reactor instrumentation

The last day of the conference was reserved for papers and discussion on reactor control problems. A. L. Gray (Plessey Nucleonics Limited) mentioned that the advent of power reactors and propulsion reactors had produced many new requirements (*13*). Neutron detectors were now required to operate under hitherto intolerable conditions of shock and vibration, humidity and temperature, and in positions which are inaccessible while the reactor is in operation, and he gave a number of examples of recent designs which had been evolved by the Plessey Company.

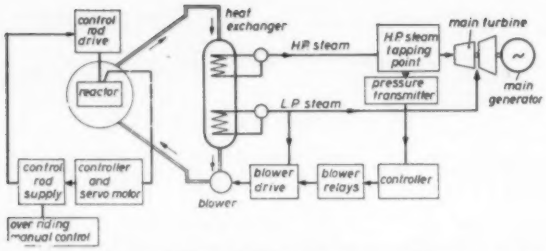
W. Abson, W. R. Loosemore and P. G. Salmon (AERE, Harwell) (*14*) described several types of fission chamber that had been developed at AERE, Harwell, for both control measurements and experimental measurements of reactor core flux distribution over a wide range of flux intensities up to 600°C (see Figs. 1 and 2). Experimental counters had also been operated at temperatures up to 900°C. Both d.c. and pulse-type chambers had been investigated and developed for high-temperature operation. Both types were operated in conditions where the ionization collection efficiency approached 100% ; in these conditions the observed response (i.e. mean current or charge per ionizing event) was insensitive to variations of such parameters as recombination coefficient and drift velocities of the charge carriers and the detectors were capable of a much greater stability and reliability of operation over a wide temperature range than other types of detectors.

R. Steinberg (National Aeronautics and Space Administration, Cleveland, USA) outlined a method of flux and power mapping in a nuclear reactor, which, by the usual activation techniques, usually requires several months, but with the method proposed could be accomplished in less than a day (*15*). The instrument is 60 in. long and 3-in. dia., and uses four fission probes which are simultaneously driven between the fuel elements (he described the application to the MTR type reactor). The probe detecting elements consisted of 10 silicon *pn* junction wafers in series, each coated with U-235. A voltage pulse, produced by a neutron-induced fission fragment results from the collection of electron-hole pairs which are formed by the passage of the ionizing radiation in the silicon. The pulse thus produced is proportional to the particle energy divided by the junction capacitance and the ionization potential of silicon. As a result of series technique, the solid state fission probe retains a relatively high counting efficiency ($\sim 1 \times 10^{-3}$ counts/neutron/cm^2) yet can still be made small enough to pass easily between the 0·01 in. spacing of the fuel plates of the MTR.

Measurements are made while the probes are in motion. The author suggested that an instrument of this type could prove a valuable addition to any research reactor. Determining the effects of control rods or new core configurations on the flux and power distribution should no longer be a problem.

G. V. Hough (Plessey Nucleonics Limited), discussing burst fuel element detection systems for power reactors, suggested a change-over from the scanning system of checking each fuel element channel in turn to methods in which all the channels are checked continuously. In this connection he discussed the application of matrix systems, but showed that for the larger reactors, other methods were preferable and discussed, in particular, the use of the new Plessey 8-channel precipitator which is being installed on the Advanced Gas Cooled Reactor.

B. Lundell and O. Rydén (A. B. Atomenergi, Sweden) dealt with a temperature measuring system they had developed for use in a pressurized water power reactor (*16*). Thermocouples are used to give temperature dependent electrical signals. These are sampled by a fast-rotating switch and



Simplified schematic for the overall automatic control of a reactor (see ref. 19) (Fig. 3)

put into an amplifier followed by a pulse height discriminator that gives a signal when any of the thermocouples measures an over-temperature. This signal is in principle used to give an alarm. The pulse train from the amplifier is displayed on an oscilloscope. To minimize the influence of false signals, some more components have been built into the system. The most important is a magnetic drum memory. The system measures about 1000 points per second and the accuracy is of the order of a few °C.

G. G. Ballard (Elliott Nucleonics Ltd) reviewed the application of transistor techniques to reactor instrumentation and described the Elliott range of transistorized reactor boxes.

O. Rydén and C. A. Bergquist (ASEA, Sweden) described a simple and cheap Xenon Predictor for high-flux reactors and R. Smart (UKAEA, Risley) described some instrumentation of the Dounreay Fast Breeder Reactor (*17*). The measuring instruments he dealt with included liquid metal flowmeters using a magnetic method, liquid level measurement using both an induction probe operating in a sealed stainless steel pocket immersed in the coolant, and a buoyancy-displacer level transmitter. Pressure measurements on the nitrogen gas blanket were made with special NaK filled Bourdon transmitters operating autosyns for remote indication. The concentration of oxides in the coolant was determined by diverting a fraction of the coolant flow through a blocking orifice meter. The metal was cooled to the temperature at which precipitation of the oxide and subsequent blocking of the orifice occurs. Corresponding measurements of the flow rate and the temperature were made and the solubility determined.

The reactor power is measured over a range of 10 decades by thermal neutron detectors situated in a graphite belt around the reactor vessel. Measurements at shut-down and during start-up are made with U-235 coated pulse detectors; for high powers boron-coated ion chambers are used. Damaged fuel elements are detected by measuring the delayed neutron emission from fission products released into the coolant stream. The reactor power is controlled by moving 12 groups of fuel elements within the core and sensitive measurements of their positions are obtained without penetrating the coolant circuit by means of servo balance coil transmitters.

Reactor control

R. I. Vaughan and R. N. H. McMillan (UKAEA, Risley) in a paper on stability studies (*18*) started a useful discussion which continued in a number of smaller groups at a later stage. Coxon (*19*) indicated that the peculiar requirements of reactor technology showed that there has been and was still scope for new developments in the measurement and indication field and the main purpose of this paper was to highlight these particular differences and show how existing proven measurement equipment was used for control in conjunction with the latest novel equipment (Fig. 3). A paper from the Rolls-Royce Company (*20*) described the steam-cooled reactor which is intended for propulsive purposes. In this case control is achieved by varying the amount of moderator in the core. B. H. Stonehouse (GEC) described the instrumentation and control features which have been evolved or improved during the last few years and are to be exploited in the 150 MW reactor currently being built in Japan (*21*). He referred particularly to the significant trend in reactor instrumentation design to the increasing use of semi-conductor devices. These are used in neutron and radiation measuring units, thermocouple amplifiers, data scanning and handling units, reactor safety circuits and in the detection of moisture in carbon dioxide. He also spoke about two data scanning problems which arise at nuclear power stations, namely scanning 600 thermocouples every 20 minutes and scanning 2000 fuel element channels in groups of six every 20 minutes. In the latter case, the GEC system involves checking the output signals from the fission product detector for both high-level and high rate of change.

Process instrumentation at nuclear power stations was dealt with by P. Hjertberg (ASEA, Sweden). He pointed out that whilst they benefited considerably from the use of similar instrumentation in chemical plants, many of the measuring instruments they wanted to use were more suitable for use in the laboratory than for use in heavy service. Only a few could operate at high temperature and pressure as required for PWR operation and much development still remained to be done.

The final two papers by D. R. R. Fair and J. McCrickard (UKAEA, Chapelcross) (*22*), and R. C. Vincent (UKAEA, Windscale) (*23*), giving a a view of operating experience, created a great deal of interest. On the whole, Vincent was able to claim a good record for the instruments supplied to Calder Hall, but was also even at this early stage able to suggest a few lessons which had been learnt.

A full account of the papers and proceedings will be published shortly in book form by Academic Press Inc., New York. No definite date is available for this publication, but it was suggested by the Secretariat that it should be available in about six months' time.

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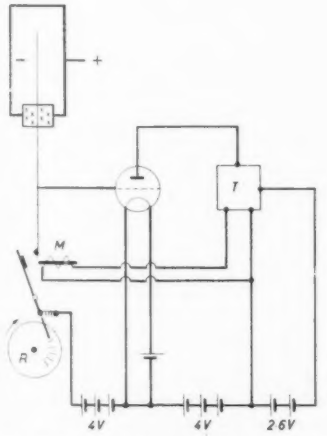
2. THE EXHIBITION

THE Exhibition associated with the International Instruments and Measurements Conference, Stockholm, was in two parts—a Scientific Exhibition held at the Royal Institute of Technology and a Commercial Exhibition held at Ostermans Marmorhaller.

Scientific Exhibition

One of the most interesting exhibits at the Scientific Exhibition was an instrument for the registration of the exposure pattern of personnel in occupational work with ionizing radiation sponsored by the Institute of Radiophysics, Stockholm. Professor R. M. Sievert was responsible for its development and he has long held the view that the biological effects of ionizing radiation may depend on the distribution of the exposure with time, and he has developed a light-weight instrument to allow this measurement. Figure 1 shows the basic circuit. The ion chamber, the walls of which are charged to a constant positive potential, has its inner electrode permanently connected to the grid of an electrometer valve. The anode circuit of the valve is connected to a transistor amplifier, which, at a certain potential of the grid, produces a sufficiently large current to operate the magnet M.



Circuit diagram of the instrument developed in Sweden for automatically registering dose rate (Fig. 1)

The magnet produces a mark on the registration paper driven by the works of an ordinary wrist watch. At the same moment, a contact device gives a fixed negative potential to the grid of the valve. The ion chamber thus changes between two constant potentials which can be selected to suit the demand of sensitivity of the instrument. For natural radiation levels a few microroentgen between the marks are sufficient and for occupational exposure a sensitivity of 0·1 to 10 mr between the marks is suitable. For emergency purposes 0·1 to 1 r per stroke might be appropriate. Instruments of different sensitivity were exhibited.

The Swedish Atomic Energy Company displayed many of the instruments described in the Conference Proceedings including a hand monitor, an electronic galvanometer and a transistorized counting-rate meter.

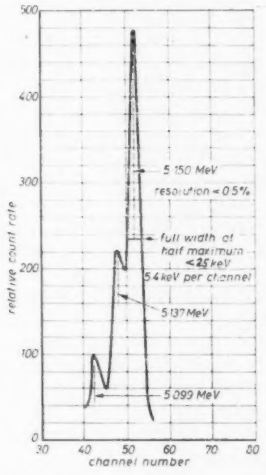
AWRE showed a range of health physics monitors, including a number of versions of plutonium monitors which took advantage of the low energy X-rays emitted by Pu-239. They also exhibited a monitor which continuously samples air for plutonium dust. Any dust is impacted on a zinc sulphide film seen by an alpha-scintillation counter. Plutonium particles of about 1 μ are more readily collected than the smaller decay products of radon and thoron. Sampling is carried out for pre-set periods (e.g. 10 min) and the integral count recorded at the end of each period. Sampling is at the rate of 18–20 ft^3 of air/min, and the integrated counts can operate bells and/or lights or reactor control mechanisms (see *Nuclear Power*, October 1960, p 105).

Another instrument exhibited by AWRE which created interest was a simple portable integrating gamma monitor for accurate survey and therapy use, weighing 2 lb and measuring $6\frac{1}{2} \times 2\frac{1}{2} \times 5$ in. A 10 cc air/argon ionization chamber is directly coupled in series with a Hamner dosimeter type electrostatic relay. This initiates a relay sequence that enables the pulse to be recorded on a mechanical register (which can be reset) in fixed integrals of dose.

Pre-selected ranges of 10 mr to 100 r or 1 to 10,000 r are available by adjusting chamber pressure from 0·3 to 30 atmos. The relay has a maximum frequency rate of 3 pulses and discharge period of 50 to 100 ms. It can be adapted for remote monitoring, uses standard components, is rugged and has *in situ* circuit tests by a rotary switch. Energy response is sensibly flat from 75 keV to 1·5 MeV.

Another instrument displayed on the same stand illustrated the further uses of radiation spectroscopy. The X-ray spectrum of Pu-239 is displayed on a cathode-ray tube using a proportional counter, and the gamma spectrum of U-235 by using a sodium iodide scintillator probe.

Analysis is achieved by sweeping through the pulse distribution of the counter coincident with the display time; base count rates up to 10,000 cycles/s and time bases up to a minute may be used. The device can be used to give counter bias and EHT voltage plateaux characteristics quickly. The exhibit illustrated a silicon junction detector used as an alpha spectrometer. Typical results are shown in Fig. 2.



Pu-239 alpha spectrum obtained with silicon pn junction detector (Fig. 2)

Another AWRE exhibit was a prototype instrument developed to measure concentrations of N-16 and Kr-85 even in the presence of gamma fields of the order of 10 mr/h, e.g. reactor gases. The assembly used has two hemispherical, compensated 600 cm^3 chambers placed symmetrically inside a cylinder large enough to give gamma compensation. The sample gas passes through the cylinder, past the nitrogen detector, then into the krypton chamber and out to exhaust. The ionization chambers are similar except for differences in their hemispherical electrode thickness, with the outer and intermediate electrodes forming the measuring half of the beta chamber. The compensating chamber comprises the inner and intermediate electrodes, the inner and outer electrodes being oppositely polarized.

To balance the system volume for gamma radiation, the centre electrodes can be mechanically adjusted. For krypton detection the outer electrode

is about half thickness (18 mg/cm²) and the centre one 200 mg/cm²—this being the total range of the Kr-85 beta particles. Beta particles from N-16 are rejected. Electrode thicknesses are chosen to reverse the situation in the nitrogen detector. Vibrating reed d.c. amplifiers measure the ionization current and, at maximum sensitivity, temperature stabilization is necessary.

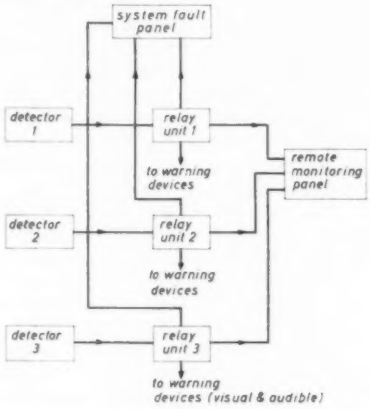
AERE, Harwell, exhibited their Automatic Beryllium Monitor described in *Nuclear Power*, August 1960, p. 104.

Another AERE exhibit was the Cadmium Sulphide Gamma Ray Detector. The conductivity of cadmium sulphide is greatly increased by gamma-radiation. Electrons in the valence band are given energy by the radiation and jump across the forbidden gap into the conduction band where they behave as if they are free. An electron leaves behind a gap or positive hole in the valence band which also behaves as a free particle. The electrons and holes move, under the influence of an applied field, sometimes being held up in localized states, or traps, until finally they recombine. A rod crystal one or two millimeters long, or a plate a fraction of a millimeter thick, mounted between indium electrodes in a probe which excludes the light, is connected in series with a battery of about 100 V and a meter. A sensitive crystal might pass 1–10 μA at a dose-rate of 1 r/h. The current flowing is a direct measure of the radiation level.

Because of difficulties in servicing contaminated equipment in process work, a pump which can operate without maintenance for long periods is necessary. A sampling pump developed for this specific duty was displayed by UKAEA, Capenhurst. The construction, of stainless steel throughout, gives very reliable operation; the useful life of the pump between overhauls is mainly governed by the rate of corrosion of the impeller.

Tests with liquid metal have shown that, in common with solid metals, electrical resistivity and oxygen are related, for example 1 ppm oxygen by weight increases the resistivity of NaK at 300°C by 100 ppm.

A simple method has been developed and was exhibited by UKAEA, Dounreay, for utilizing this effect by making resistivity measurements to high stability (1 part in 10,000) with liquid metal flowing in a pipe at operating temperature.



Schematic of the criticality incident detector monitoring system developed by AVO Ltd (Fig. 4)

Compensating for temperature effect is particularly important as 100 ppm resistivity change is produced by only 0·04°C change in NaK temperature; compensation has extended this range 700-fold to 25°C.

Oxide particles passing through the measuring pipe can be clearly seen as pulses on the recorder chart, so the meter can also indicate whether the oxygen content is above or below the saturation level and can determine the saturation temperature.

Commercial Exhibition

The UKAEA also exhibited at the Commercial Exhibition. A general view of their stand is shown in Fig. 3, which shows some of the equipment developed for use at Dounreay as well as the b.s.d. developed by Plessey Nucleonics Limited for use at Chapelcross. The b.s.d. exhibit also included the Plessey equipment for the AGR. This provides a continuous check on every fuel element channel in the core and gives immediate identification of any containing a faulty element. Thirty-two precipitator chambers in four, eight-chamber units are used and design advances have been such that each eight-chamber unit is smaller than a single-chamber Calder unit.

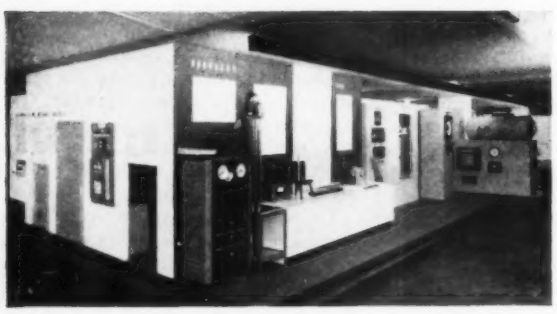
Another interesting exhibit was the Contactless Level Detector for Liquid Metal. This measures the levels of liquid sodium and sodium-potassium alloy in various tanks in the coolant system. Two identical transformers, one above the other, are lowered into a stainless steel pipe in the tank. They are so connected that when the bottom transformer is lowered to the level of the liquid metal its secondary voltage decreases and no longer balances that of the top transformer. This out-of-balance voltage increases until the top transformer reaches the level of the liquid metal when it reaches a maximum. Another UKAEA Exhibit which created a great deal of interest was the Reactor Simulator.

Many British commercial firms had stands that supported the AEA. These included Ultra Electronics Ltd., who exhibited their Temperature Trip Amplifier, based on the use of a magnetic amplifier, Avo Ltd., who displayed a number of the radiation monitoring instruments, including their criticality incident detector monitoring system shown schematically in Fig. 4, and Plessey Nucleonics Limited, who displayed a range of contamination monitors as well as a range of their latest b.s.d. equipment for power and research reactors.

General Radiological Ltd. exhibited their Gamma Monitor type 1638A, which is another instrument typical of recent trends. This unit is designed to energize an alarm circuit if a dose of gamma-radiation exceeding 100 μr is received by an ion chamber in less than a pre-fixed time interval. A number of these units can be used with a supervisory control centre. Up to twelve monitors in any one area are grouped at the Control Centre and associated with the Alarm Signal for that area.

20th Century Electronics Ltd., Tracer Lab. and Plessey Nucleonics Ltd. exhibited a range of radiation detectors, the former firm displaying many of the high-temperature fission counters described by Abson, Loosemore and Salmon at the Scientific Conference.

The General Electric Company had a large stand devoted to their nuclear activities, including the b.s.d. equipment they were building for the Tokai-Mura Station, as well as their digital data-handling systems.

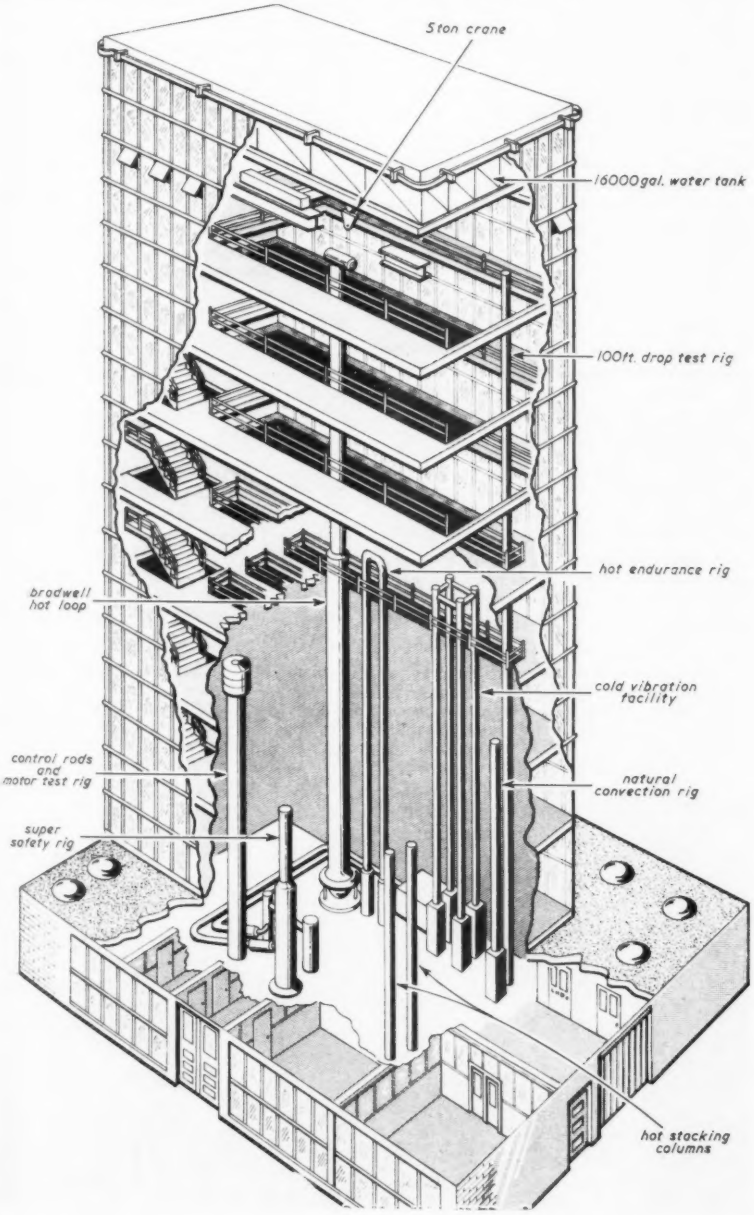


A view of the UKAEA stand at the Commercial Exhibition (Fig. 3)

Fuel element test tower

For developing fuel elements for Bradwell and later CEGB reactors, Parson's 120 ft tower has rigs for the study of vibration, deformation, thermal bowing and other design problems

THE WORK THAT TAKES first place at Parson's £M2 Nuclear Research Centre is the development of reactor fuel in all its aspects. With a staff of some 400, 90 of whom are graduates, some of the many problems the Centre is looking at are the attainment of maximum heat extraction from nuclear fuel and the search for improved materials and component design. The 120 ft test tower, around which much of the work is centred, provides sufficient height for operations relating to reactor control, mechanical behaviour of fuel elements and many other investigations.



In a three-element cold vibration facility, which is made up from mild steel channelled sections separated by polished Perspex spacing rings, single and stacked elements are exposed to circulating cold CO_2 at densities and mass flows equal to those obtaining in a reactor. Gross movements of the elements in the gas stream can be observed through the Perspex windows, whilst fine movements are measured by capacity probes, accelerometers and strain gauges.

A twin-limb hot gas rig provides mild steel and graphite channels in which fuel elements, exposed to CO_2 flows of the order of 4 lb/sec and up to 430°C, can be endurance-tested to check their resistance to deformation when acted on by gas forces. One of these hot limbs, the Bradwell loop, provides an assembly of graphite blocks pierced with four adjacent channels of size and pitch equal to that in the Bradwell reactors. The pipe work above this simulates the space up to, and above, the charge floor and includes a charge-discharge valve. Using a string of connected and thermocoupled fuel elements, the operation of separating and discharging each element simulates reactor conditions.

Another graphite channel rig, the natural convection rig, is designed for the measurement of heat transfer characteristics of fuel element cans at low gas flows. The main object is to study temperature distribution if the coolant circulation fails. The cans, entirely heated by means of stainless steel tubes carrying electric current, lose heat by natural convection and radiation to the channel wall.

In a further rig, long-term bowing of the elements and end assembly distortion are being investigated, in a closed column containing CO_2 at reactor pressure and with the temperature graded up the column to correspond to reactor conditions.

The 100 ft drop test rig enables fuel elements to be dropped on to other fuel elements and support struts for the purpose of determining the ability to withstand shock of the shock-absorbing device at the bottom of each channel.

The motor test rig is being used by Reyrolles for life tests on control head motors subjected to repeated operation under conditions of differing CO_2 and moisture content. In addition to this facility for making life tests on control rod assemblies, there is a rig for testing safety devices which comprises a hot CO_2 circuit into which additional electric heating can be switched at will. This produces a controlled temperature excursion in the gas, thus causing the safety device to operate.

STUDENTS' NOTEBOOK

GROUNDWORK—Radiation

What safety regulations exist in research laboratories?

Apart from the Nuclear Installations Act, 1960, which covers the licensing of reactor sites, there are no Government regulations that control the handling of radioactive substances in industrial or educational research laboratories. For other organizations, under the Factories Acts, 1937 and 1948, special regulations are being drafted covering the use of sealed and unsealed sources emitting ionizing radiations. The problem of radioactive wastes, however, is covered not only by the Radioactive Substances Act, 1960, but also by earlier public health legislation, with the local authority acting as the responsible body for inspection.

In all, some 750 establishments receive deliveries of radioisotopes and of these over 100 are university laboratories. Another 170 include trade and research associations, technical colleges and schools. The fact that no official legislation exists to govern their activities does not mean, however, that care is not taken. In many cases, an internal code of practice has been drawn up for the protection of personnel against radiation hazards. They have relied to a large extent, partly on the established practices of research organizations with good records, and partly on the recommendations of the International Commission on Radiological Protection, a body that has been functioning since 1928, and whose recommendations, continually under review, represent the best of international concepts and practices.

The Imperial College of Science and Technology, London, was one of the first to formulate a Code of Practice, a publication which has now reached its third edition. Queen Mary College and several other London Colleges have followed this code. Cambridge has compiled a series of notes and these have been adopted by Birmingham. A more comprehensive code is expected shortly, however, for application to all universities, one that has been compiled for a Committee of the Vice-Chancellors and Principals. Whilst the points raised in it will not be binding, it is assumed that recalcitrant bodies will be told quietly to toe the line, rather than force the possibility of Government intervention, a step no university or college could be prepared to accept.

For technical colleges and schools, the responsible body for safety is the local educational authority, or governing body, if relevant. Proposals for the use of sealed or unsealed radioactive sources have to be reported, however, to the Ministry of Education or to the Scottish Education Department, both of whom have a Radioactive Substances Education Panel to watch developments and advise the local authorities. With this responsibility, the Ministry has issued a revised series of 'Notes for the Guidance of Technical Colleges', one part covering X-rays and sealed substances, and a second part covering unsealed radioactive sources.

All codes and forms of guidance follow a general pattern: they recommend a responsible safety officer; lay down a classification for radioisotopes according to radiotoxicity; and delineate types of laboratories, indicating essential design requirements. They then stipulate methods of handling and storing materials, advise on the disposal of active waste and, finally, indicate the emergency procedures to be adopted.

BOOKLIST—Radiochemistry

Nuclear and Radiochemistry. G. Friedlander and J. Kennedy. Wiley, 1955. A good advanced treatment that deals mainly with theory. It includes relatively little practical radiochemistry and is not recommended for beginners.

Modern Radiochemical Practice. G. B. Cook and J. F. Duncan. Clarendon Press, 1952. No previous knowledge of radiochemistry is assumed; the emphasis is mainly on practical aspects of the subject, with descriptions of a good selection of experiments. The counters described, however, are somewhat out-of-date.

Radioisotopic Laboratory Techniques. R. A. Faires and B. H. Parkes. Newnes, 1958. A well-written elementary practical book, suitable for the chemist and technologist that has no special training.

Radioisotopic Techniques. R. T. Overman and H. M. Clark. McGraw-Hill, 1960. Covers all aspects of the principles and practice of the applications of radioisotopes in chemistry. It is strongly recommended to the chemist wishing to use isotope techniques.

Chemistry of the Actinide Elements. G. T. Seaborg and J. Katz. Methuen, 1958. This is the best available book covering all aspects of the chemistry of the actinide elements. Half the book is devoted to uranium and plutonium. Literature coverage is good and is taken up to 1958.

Chemistry of the Rare Radioelements. K. W. Bagnell. Butterworths, 1957. A specialist treatment of the chemistry of the elements polonium to actinium.

NEWSBRIEFS

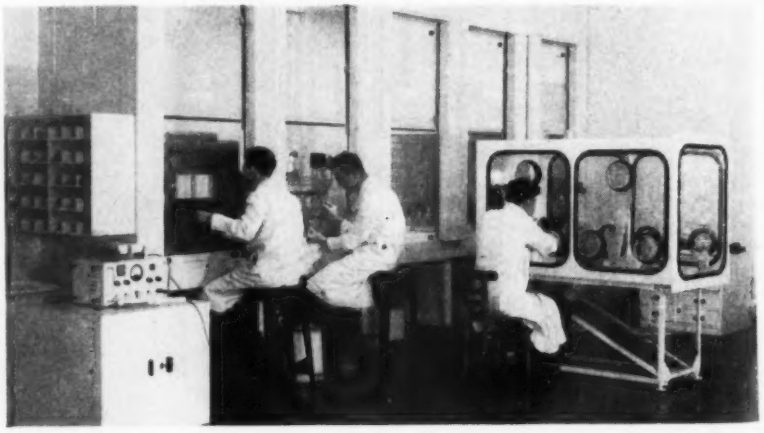
- Manchester and Liverpool Universities, it is understood, are to share a research reactor, possibly a 100 kW Jason, sited at the UKAEA, Risley. Authority staff will act in a consultative capacity. It seems that the scheme is held up awaiting Treasury sanction.
- Scotland's educational establishments are most likely to have a combined reactor facility sited in Glasgow, possibly at the Royal College of Science and Technology. The choice lies between designs submitted by AMF, American-Standard and the Hawker-Siddeley Nuclear Power Co. National Institute approval and grants-in-aid may well be a long way off, however.
- The Advisory Council of Scientific Policy, in their annual report, urge greater co-operation between universities, colleges of technology and government establishments, with more concentration of effort on expensive scientific research projects.

UK COURSES

Borough Polytechnic, London Nuclear Power Technology: 12 evening lectures commencing January 12, 1961. Nuclear Particle Techniques: 15 evening lectures commencing January 11, 1961.

Lanchester College of Technology, Coventry Recent Advances in Solid State Physics: October 27–28. Fee: 22s.

The nuclear technology laboratory at the Imperial College is used for work involving beta and gamma isotopes (in hundreds of millicuries) and for plutonium handling (200 mg quantities). The fume hood (left), where Zr-95 is being handled, has a 2 in. brick shield, remote handling tongs and a lead glass viewing window. The glove box (right) contains 200 mg plutonium. Students wear laboratory coats and overshoes. Note the monitor, close at hand, on the cupboard



Radiation resistant grease

gamma test rig at Harwell

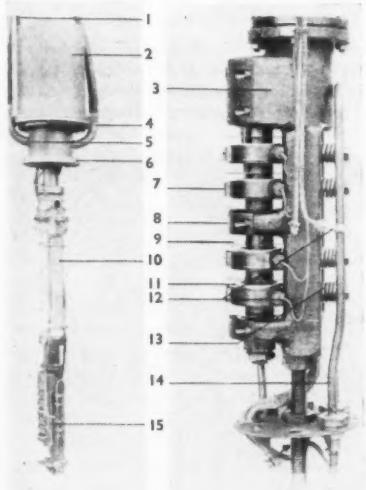
MOBIL Oil's test rig SETRA (submerged, elevated temperature, irradiation apparatus) is the first dynamic grease rig to run under simulated high flux reactor conditions. Operating at Harwell's Fuel Element Irradiation Pond (see page 95 this issue) it is possible to obtain, in a few weeks, gamma doses equivalent to a year's exposure in a reactor.

The rig consists of an electric motor, contained in the housing (2), driving a bearing and gearbox test assembly (15) by means of a drive shaft inside the extension tube (10). Carbon dioxide passes down to the bottom of the test assembly by means of the CO_2 supply tube (1) and returns through the conduits (4) and (5) which also contain the power and instrumentation cables. The extension tube and test assembly fit inside an irradiation sample can which is sealed by an adaptor (6).

An enlarged view of the test assembly (15) reveals a test gearbox casing (3), the gear driving a shaft at 900 rev/min. Four test bearings, contained in housings (7) are loaded by means of 'screw-down' springs (13) attached to the housings. The bearings are fitted with seals (11), but in the event of any slight leakage, seepage throwers (9) are fitted to the drive shaft to prevent contamination of bearings underneath. The temperature of the test assembly can be adjusted by means of heaters (14) up to 250°C, and the test bearing and ambient temperatures recorded by means of thermocouples (12). There are three sealed slave bearings, one inside the gearbox housing (3) and two in the other housings (8); the slave bearings can also be used to test greases if necessary.

The whole apparatus is submerged and located at the bottom of the Fuel Element Irradiation Pond, where spent fuel elements from Dido and Pluto are arranged around the bottom of the irradiation sample can to provide the desired gamma flux. The test assembly is at the bottom of the sample can where up to 3 megarads/hour can be obtained. The electric motor is located as far as possible from the bottom in order to minimize radiation damage to the windings, etc.

Failure of a grease is indicated by a rise in temperature, but there is also an overload 'cut-out' on the motor for the unlikely event of excessive grease stiffening before a temperature rise. So far, products have been tested to radiation levels exceeding 1000 megarads.



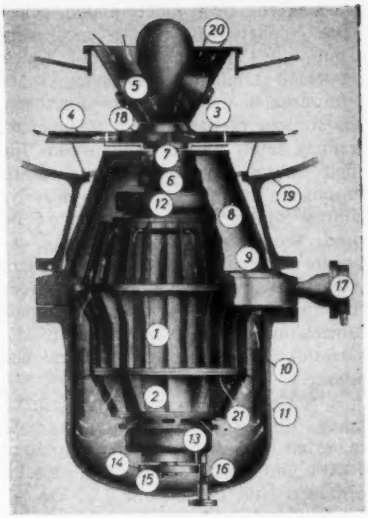
Development of radiation resistant oils and greases require gamma facilities. Using the Setra rig (shown here without its housing), Mobil have been carrying out tests at Harwell since June

Circulators for AGR

uses submerged motors

The circulation of CO_2 through Windscale's Advanced Gas Cooled Reactor, is controlled by four circulators, each of Howden design and manufacture. Each circulator is only 36 in. in diameter, but it absorbs 1520 h.p. and raises the gas pressure by 281 lb/in^2.

The driving motors consist of a 1570 h.p., 2970 rev/min main motor and a 40 h.p. pony motor with a 600–1800 rev/min speed variable. Contained within Class I pressure vessels attached to the main heat exchanger pressure vessels, they form an integral part of the high pressure circuit. The motors, which are of vertical spindle design, have special insulation and sleeve and thrust bearings designed to operate entirely immersed in the high pressure CO_2.



Main CO_2 circulator for AGR. 1. main motor 2. pony motor 3. aerofoil bladed radial flow impeller 4. vaned diffuser 5. variable inlet control vanes 6. standstill seal 7. stub shaft 8. ss insulation 9. pressure vessel 10. removable pressure bell 11. motor cooler 12. Michell journal and thrust bearings 14. rota brake 15. impeller removal device 16. standstill seal operating spindle. 17. terminal box 18. heat trap 19. main heat exchanger vessel 20. main CO_2 circuit 21. motor cooling circuit

With the main motors running at constant speed, the circulator output is controlled by a high duty inlet vane mechanism. By this means, a complete range of duties is obtained efficiently without stall or surge. The design of the vane allows for arduous conditions of high temperature, extremely dry environment and the necessity for avoiding the use of lubricants of any kind.

By using submerged motors and bearings, the need for rotating shaft seals is avoided and the danger of gas leakage from the reactor circuit is eliminated. To allow ease of maintenance, the motors can be entirely removed and examined without depressurizing the main CO_2 circuit.

Cobalt-60 radiography

high specific activity

Cobalt-60 sources for radiography with the extremely high specific activity of 100 curies/gramme are now being prepared by Atomic Energy of Canada Ltd.

These sources, marketed by Watson,

are made up from nickel plated, cylindrical pellets of cobalt measuring 1 mm × 1 mm, which are double sealed in welded stainless steel capsules.

Because of the high specific activity, the sources prepared from it have extremely small physical dimensions for their output, enabling sharper radiographs to be made or, alternatively, shorter source to film distance to be used, thus considerably reducing exposure times. A further advantage, particularly with the kilocurie sources for radiography, is that the small dimensions give a lower degree of the wasteful self-absorption within the source.

A wide range of standard sources made up from 100 curies/gramme materials is readily available up to 20 c. 1000 c and 2000 c sources can also be obtained with dimensions 1·25 cm × 1·6 cm and 1·52 cm × 2·5 cm respectively; 150 curies/gramme sources will soon become available.

Reactor direct conversion feasibility proved

Both General Dynamics and Westinghouse have had some success in their programmes for the direct conversion of heat to electricity. In both cases the converters were built into a fuel element and inserted into a reactor.

The ultimate aim is to overcome the significant inherent power losses in nuclear power stations, caused by the large temperature drop from the centre of the fuel elements to the outside surfaces in contact with the cooling water. While some fuel elements themselves reach temperatures above 4000°F, the limits to the useful amount of heat which can be taken from the fuel are at about 600°F.

Using the Triga reactor, 90 watts of electric power, at a power density of 21 W/cm², was produced from a caesium cell converter which contained a fuel element made up of uranium carbide and zirconium carbide. The conversion of fission heat to electrical energy, as measured at the bus bar outside the reactor during the tests, showed overall efficiencies as high as 10%, at an operating temperature of about 3500°F. Further increases in efficiency are considered possible when the dimensions and temperatures of the cell are optimized.

The caesium cell thermionic-emitter element used in the reactor utilizes fully enriched U-235. The electrons, created by the heat of fission, are collected by an electric current collector, surrounding the emitter electrode. Caesium vapour, in the gap between the emitter and the collector, is used to enhance the rate of power production.

The entire assembly was housed in an aluminium can, identical to that used with the regular Triga fuel element. Two heavy conductors were used to deliver power from the cell to an instrumented load at the top of the reactor pool.

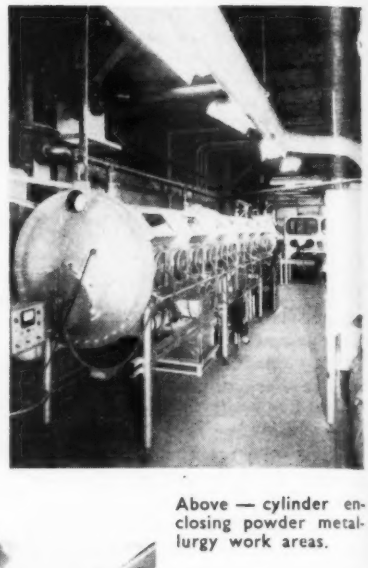
In the Westinghouse experiment, a fuel element was built with the thermionic generator in its centre and a thermoelectric generator surrounding it. Operated in the Westinghouse Testing Reactor, the generator produced about one watt of power.

Both methods of converting heat directly to electricity operate on similar principles, but operate most efficiently at widely divergent temperatures. A thermionic generator operates at about 3500°F but will not function efficiently at temperatures below 2700° F, whilst a thermoelectric unit does not operate at such elevated temperatures, but works well in the temperature range of 600° to 1800°F.

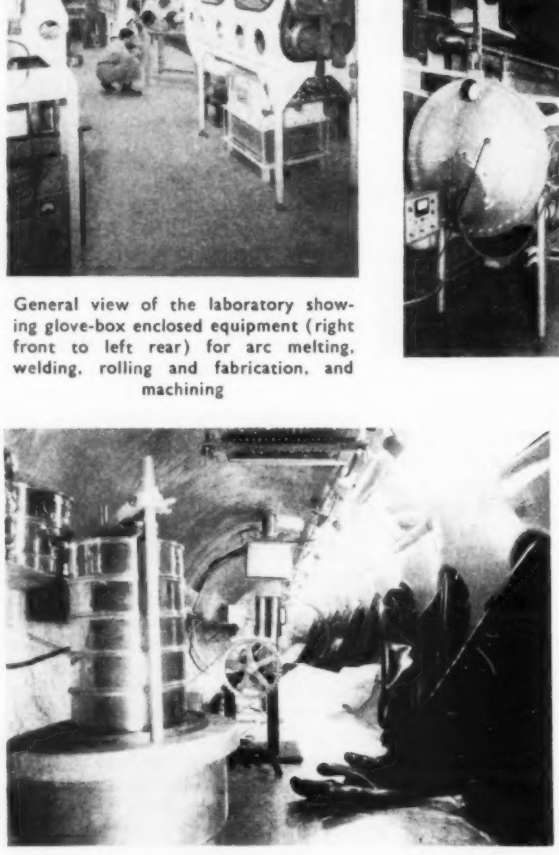
By putting the two types of generators in tandem, the heat passing through the thermionic generator flows through the thermoelectric unit. The elements are wired in series to give a combined electrical output over a very wide temperature range.

Plutonium studies at Battelle

General view of the laboratory showing glove-box enclosed equipment (right front to left rear) for arc melting, welding, rolling and fabrication, and machining



Above — cylinder enclosing powder metallurgy work areas.



Left—interior of powder metallurgy cylinder prior to installation of equipment.

Battelle Memorial Institute are now operating their own plutonium laboratory, the first in the US to be privately financed. Facilities have been provided to conduct metallurgical studies such as melting, rolling, machining, powder metallurgy, metallography, determination of properties, and physical and chemical investigations. Similar facilities have been available at Argonne for over a year but they are primarily associated with a plutonium fuel fabrication facility (see October 1959 'Nuclear Power', page 108)

Sodium reactor steels
promising h.t. alloy

For sodium coolant systems, operating at 1100–1150°F, ferretic chromium-molybdenum steels have certain advantages over austenitic stainless steels. They are less expensive, have higher coefficients of thermal conductivity, low coefficients of thermal expansion and are resistant to stress corrosion in hot water or steam contaminated with chlorides.

Disadvantages, however, include lower high temperature strength, a tendency to decarburize in sodium systems containing austenitic steels, and the need for post-weld heat treatments. An alloy modification is therefore required to increase their high temperature strength.

Atomics International, in their alloy development programme, have produced a 2·25% Cr–1% Mo–0·4% Cb–0·4% Ti alloy that shows promise. Preliminary tests indicate that the short time tensile, creep and stress rupture properties are equivalent to Type 403SS at temperatures of at least up to 1100°F. In a sodium system, this steel was found to be neutral to 304SS as far as carbon transfer was concerned.

The initial goal in this programme is to provide a material for piping and pressure vessels external to the reactor core. Use of the material inside the core will depend on the results of future irradiation damage studies.

Measuring strain
UKAEA development

An ingenious extensometer for measuring strain in inaccessible structures such as reactor pressure vessels, where high working temperatures rule out ordinary strain gauges or extensometers, has been invented by Mr W. M. Irvine of the AEA, Risley. It consists essentially of a resonant cavity with a timing plunger rigidly attached to the extending surface. A coupling loop connects the cavity with an oscillator whose frequency thus deviates from its normal 150 Mc/s with variation of the surface strain of the structure. The invention also includes the employment of the device with a simple transmitting circuit applicable in any circumstances where temperature is not excessive and strain has to be measured in an inaccessible component, for example, a component buried in the ground, embedded in thick concrete or sunk in deep water.

Accelerator liner for Nimrod
first of its kind in UK

A further stage in the development of Nimrod, the giant synchrotron (atom smasher), which is being built next door to Harwell, was reached when work on the first radio frequency liner for the Nimrod synchrotron was completed. Built by the London Aluminium Co., its job will be to accelerate protons from 600 KeV to 15 MeV. (*See Business p. 120.*)

Manufactured from 10g high conductivity copper made up from sheet and manually welded by the argon arc process, the liner, which has an overall length of 44 ft, is 7 ft in diameter and weighing some 5 tons, had to be constructed with considerable care to ensure that no distortion took place.

It is basically a closed cylindrical copper tube reinforced by a series of centrifugally cast stainless steel rings and longerons, thus enabling the loads due to its own weight, and that of the drift tube assemblies, to be transferred through the copper shell to the liner supports.

ENRICO FERMI BALL VALVE. A 500-lb uranium ball for a special ball valve to be used in the Enrico Fermi reactor, has been machined into a perfect sphere by Hydromatics. Made of spent uranium with a safe level of radiation, the ball has a 10-in. bore in which it will receive contaminated uranium fuel rods from the reactor's core. Turned to the closed position, the ball then becomes an effective shield against radiation from the rods. Forming the access port of the cask car, the valve in which the ball fits is wheeled to a pipe line and hooked up by remote control. The rods are steam cleaned and the fuel is returned to the reactor.

IN BRIEF

RADIOGRAPHY FOR CONCRETE A 7·5 curies cobalt-60 unit, designed by Pantak, was recently used to examine the 6 in. thick concrete walls of the new Dungeness lighthouse. Kodak-D film was used with an exposure time of 70 minutes.

★ 280

ACCELERATORS FOR SCOTLAND For cancer treatment, two Glasgow hospitals are each to have a 4 MeV linear accelerator charged with 2,000 curies cobalt-60 source. AEI are making the machines.

★ 281

ORNL'S WIGNER RELEASE Oak Ridge's Graphite reactor, X-10, operating since 1943, has had its first annealed operation for the removal of stored energy. Taking three days, the cooling and flow was reversed and reduced to one half its normal rate of 100,000 ft³/min. Hundreds of extra thermocouples were added for fuel and moderator safety checks.

★ 282

DATA PROCESSING. A development of the IBM 709, the transistorised 7090 data processing system, computes five times faster and is capable of adding over 13 million figures a minute.

★ 283

ELECTRONIC MAGNESIUM OXIDE Semi-Elements have developed an ultra-pure magnesium oxide that may well prove to be a future high temperature semi-conductor material. Another application is its use for detecting high radiation fluxes. It has a high melting point of 380°C., is stable, insoluble in water, and is easy to machine and fabricate.

★ 284

HEAT EXCHANGERS VKW of Dusseldorf are carrying out tests on the problem of obtaining maximum tightness of heat exchangers and the method of exact measurement.

★ 285

STEAM COOLED REACTOR US patent 2,936,273 presents a design where the formation of vapour bubbles, as a result of a neutron flux excursion from the injection of a reactivity increment, will nullify the reactivity increment and create safe operating conditions.

★ 286

SUPERHEATING US patent 2,938,845 relates to a BWR where the water coolant is boiled on the outside of tubular fuel elements and the steam is superheated on the inside.

★ 287

HIGH TEMPERATURE PHOTOEMITTER A new photoemitter using a semi-transparent combination of antimony, potassium, and sodium has been developed at Westinghouse. It has shown stability after 140 hours operation at 120°C.

★ 288

★ *For further information on any item, circle the appropriate number on the reply card facing page 162.*

Points from Papers

reports, meetings, conferences

CHEAPER SEPARATION

Comparing the investment costs and power consumption of the gaseous diffusion method and gas centrifuge processes for isotope separation, Mr Gernot Zippe of the University of Virginia concludes that the German 'Degussa' model investment cost is similar to that of the gas diffusion method. He assumes that the efficiency of the Degussa separating process can be increased by a factor of three.

Using the gaseous diffusion costs and comparing them with the 'Virginia' centrifuge, he concludes that the latter's specific investment cost would be about 25 times higher than the corresponding value for gas diffusion. However, the cost per unit in the US might come down by as much as a factor of 2 if one tooled up to produce the machine in large numbers. On separation tests, the power consumption would be about 10% of that of the gas diffusion method. Extrapolating to the 'Degussa' machine, which costs about £75, brings the investment cost down.

Potential of the short bowl gas centrifuge for the enrichment of the U-235 isotope as compared with published figures for gas diffusion. Gernot Zippe. USAEC 1960. *Report TID-5735.* 10 pp. Available from OTS or depository library (microcard).

ALTERNATIVE EXTRACTANT

Results in Tables 1 and 2 below give partition data obtained under identical conditions using 20% DAAP/OK (di n-amyl n-amyl phosphonate) and 20% TBP/OK. These results show that DAAP is the superior to TBP for U and Pu recovery, but since it extracts gamma-emitting impurities more strongly, more stages are needed to achieve the required amount of decontamination. Because of this, DAAP is not a favourable alternative solvent for processing fuel elements.

The use of di-amyl amyl phosphonate (DAAP) as an alternative extractant to TBP. L. E. Marc de Chazal and A. R. Lister AERE Harwell. *Report AERE M698.* 2 pp Available from HMSO 1*s* 2*d*.

POCKET DOSIMETER

This small, rugged instrument was designed because of the need for a direct-reading personal gamma dosimeter, with a sensitivity of about 20 mR, suitable for carrying in a coat pocket. The instrument uses a simple condenser ionization chamber. The self-capacitance of the electrodes provide the necessary charge storage and the voltage drop, measured by a single electrometer valve circuit, is directly proportional to the gamma dose. Figure 1 gives a view of the instrument.

A sensitive direct-reading pocket-size gamma dosimeter. J. H. Howes. AERE Harwell. *Report AERE R3115.* 11 pp. Available from HMSO 3*s*.

NEUTRON TEMPERATURE

The slow variation of moderator temperature (closely related to neutron temperature) during a fuel temperature transient is valid only when the graphite in the lattice is in good thermal contact. This condition is not fulfilled in some advanced reactor designs where moderating material is introduced into the channels. Preliminary work is described in this report on the temperature of neutrons reaching a fuel element surrounded by graphite sleeves.

Neutron temperature in reactors having moderator closely associated with fuel elements. R. G. Freemantle and J. S. Harper. AERE Harwell. *Report AERE M712.* 11 pp. Available from HMSO 2*s* 6*d*.

OXIDATION OF UO_2

Semi-quantitative experiments investigating the stability of UO_2 in contact with water vapour under irradiation indicate that oxidation is brought about mainly by oxygen produced during radiolytic decomposition of the water vapour. The data were limited to temperatures of 80°C and water vapour pressures below one atmosphere. An estimate based on pessimistic assumptions suggests that the rate of oxidation of pellets in defected cans in a steam-cooled reactor will be low.

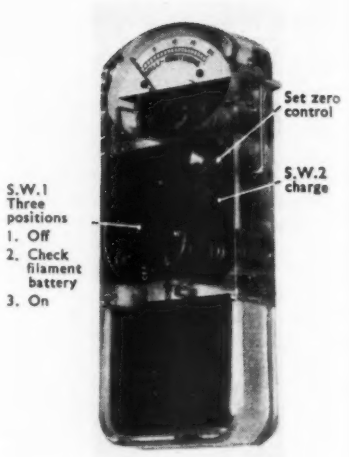


Fig. 1 General view of the pocket dosimeter

The oxidation of uranium dioxide by water vapour under reactor irradiation. B. R. Harder and R. G. Sowden. AERE Harwell. *Report AERE M725.* 15 pp. Available from HMSO 3*s*.

New Reports

Ion exchange reviewed as a continuous process. K. R. Poole. AERE Harwell. *Report AERE R3022.* 11 pp. Available from HMSO 2*s* 6*d*.

Strontium-90 in human bone in the UK 1956–1958. N. T. J. Bailey, F. J. Bryant and J. F. Loutil. AERE Harwell. *Report R3299.* 40 pp. Available from HMSO 6*s*.

Atomic research and development, the role of industry. A report prepared by the Atomic Industrial Forum staff. Feb. 1960. 9 pp.

Civilian Power Reactor Programme. Part III. Status report on pressurized water reactors as of 1959. *TID-8518(2).* 86 pp.; Status report on aqueous homogeneous reactors as of 1959. *TID-8518(3).* 184 pp. Available from the Superintendent of Documents, U.S. Government Printing Office. $1·25 each, or depository library.

TABLE 1 *Partition data for 20% TBP/OK and 1N HNO_3 aqueous solution*

DETERMINATION	URANIUM CONTENT, mg/ml Aqueous phase	Solvent phase	Ku	ALPHA, cpm/ml Aqueous	Solvent	Kα	ESTIMATED Kpu	GAMMA, cpm/ml Aqueous	Solvent	Kγ
1	26·4 21·8	40·8 42·9	1·55 1·97	$3·5 \times 10^4$	$1·7 \times 10^4$	0·49	0·35*	$4·0 \times 10^6$	$9·0 \times 10^5$	$2·5 \times 10^{-4}$
2	5·43	20·4	3·76	$2·6 \times 10^4$	$1·0 \times 10^4$	0·39	0·29*	$3·9 \times 10^6$	$1·5 \times 10^5$	$3·8 \times 10^{-4}$

TABLE 2 *Partition data for 20% DAAP/OK and 1N HNO_3 aqueous solution*

DETERMINATION	URANIUM CONTENT, mg/ml Aqueous phase	Solvent phase	Ku	ALPHA, cpm/ml Aqueous	Solvent	Kα	ESTIMATED Kpu	GAMMA, cpm/ml Aqueous	Solvent	Kγ
1	20·6	48·6	2·36	$2·7 \times 10^4$	$2·5 \times 10^4$	0·93	0·71*	$4·6 \times 10^6$	$3·3 \times 10^5$	0·07
2	1·91	21	11	$2·1 \times 10^3$	$1·9 \times 10^4$	9·1	8·9*	$3·7 \times 10^6$	$1·3 \times 10^6$	0·35

**The partition for plutonium was obtained by taking the alpha count, due to uranium solution used, from the alpha counts found in the aqueous and solvent layers.*

Cross Section by GRACCHUS

THE WEAK dribbles of information that come from our somewhat care-encrusted AEA must be frustrating for anyone in industry who is working on advanced gas-cooled reactor studies. Not only is the information that is eventually passed on by the Authority sometimes over a year old but it apparently has to be specifically asked for by industry. The absurd position is reached with only the AEA knowing what stage progress has reached and industry having to guess and then ask for information on the basis of that guess. Happily there appears to be a loophole—though a somewhat torturous one. The solution is to ask the USAEC for information on AGR work; I have often heard responsible reactor designers say that US firms are better informed on the AGR than their British counterparts because of the excellent liaison service between the AEA and the AEC, the latter passing the data on.

THE FIVE firms who have put so much effort, with only the hope of future gain, into the Ministry of Transport ship tenders, may well find that they have been led up the proverbial garden path. The date when the official views are to be announced is said to be 'soon' (March–April is my guess) but it would not surprise me to read that a 'go-slow' policy on nuclear ships has been declared and that the aim is accelerated research and development before any actual building will take place. This will merely be an extension of the Government's cautious view over nuclear policy.

The reactor concept to be chosen is another question waiting to be answered. It would not surprise me to see an all-British design put over; that leaves only the Hawker Siddeley OMR (apparently favoured by the Winfrith assessment team) or the Rolls-Royce steam cooled heavy water design. The Rolls-Royce design was not requested by the Ministry but I hear that work has been going steadily forward and that the economics are very attractive. The Ministry, while it is not bound to accept any of the five proposals submitted, will no doubt have in the back of its mind that when the American equipment for the *Dreadnought* was purchased, it set back work on the British submarine reactor at Dounreay by almost a year. Officialdom should also note that W. Germany is starting marine reactor work next year.

THE RECENT IAEA conference on small and medium reactors has again emphasized the comparatively small effort this country is making in this field. At some stage in the future, I hope the indifferent official attitude will give way to something more positive; needless to say, I think it should be as soon as possible. I only hope the AEA is still not keeping to its survey of the market for small reactors made by the Economics and Programming Branch late in 1958 and circulated in confidence among leading industry executives. This drew the conclusion that such information as the AEA could obtain without an extensive market survey suggested that the potential market for 'small' reactors was considerably less than for large reactors. I would only point out that there is now almost no export market for large reactors. I also found the survey too full of remarks like 'a more complete analysis (about conventional generating costs in less industrialized countries) would involve the collection of more data . . . which would take a considerable amount of time and effort.'

One problem that may face developers of small reactors is an adequate supply of enriched uranium. Indications are, however, that it will soon be there for the asking—at American prices. The USAEC will soon have more than enough to meet their foreseeable needs and the IAEA is still waiting for offers for its supply. Perhaps then the AEA will be able to give a firm price for enriched uranium. The quoted figure in reply to one recent query was £105,000–£200,000 a tonne; the Authority could not give a more exact figure until firm orders were received—but it is unlikely that they will get orders until they quote a firm price.

An interesting feature of the IAEA conference was the absence of the Russians in any strength. One last-minute paper was read—a not too new one at that—and I didn't see the authors again. It struck me as just a 'showing the flag' attendance. If so, it was a pity; one would have liked to have heard more about Russian developments in this field.

I WAS interested to hear at Hunterston recently a leading GEC official confirm that he did not expect the company to get the CEGB contract for Sizewell (English Electric are tipped—see *Worldview*, October, p 69).

The GEC tender is reported to have been the lowest (£90/kW), but I suspect that the hollow fuel elements used by the GEC are not over popular with the AEA who, I understand, guaranteed those for Tokai-Mura while feeling that they had not really had a chance to test them. The AEA naturally enough would like to see a standardized fuel element but judging from the trouble they are having with the Bradwell and Berkeley elements, this attitude seems just a little optimistic. I should have thought it would have been better to have made an even more intensive effort on fuel element design.

Incidentally, I hear that English Electric's design for Sizewell is likely to incorporate two reactors in one building surrounded by eight heat exchangers. This follows their unsuccessful design proposal for Dungeness. I do not know the cost yet (no doubt it was discussed at the CEGB-English Electric questionnaire meeting in October) but Hunterston, which will be in full operation by the autumn of 1963, will have an initial capital cost, less fuel, of £155/kW. The South of Scotland Electricity Board estimate the cost of electricity per unit from the station at about 0·63d against 0·59d for the new coal station at Kincardine-on-Forth.

IS THERE any significance in Harwell taking a holiday on October 10? This date (the Double Tenth) is the anniversary of the founding of the Chinese Republic by Sun Yat Sen in 1911. The official explanation is that the holiday is one of the nine privilege days Harwell has, the others being taken up by normal public holidays during the year.

New Product Survey

EQUIPMENT · INSTRUMENTS · MATERIALS

GAS PURIFICATION

oxygen decontamination

The 'Nilox' gas purification system, developed by Southern Instruments for laboratory use, provides a continuous stream of hydrogen, nitrogen, argon and other gases, almost completely freed of oxygen. An oxygen content of 2000 p.p.m. in ordinary commercial nitrogen, for instance, can be reduced to 0·2 p.p.m.

After the major part of the oxygen is absorbed by an organic reagent, the gas passes to a scrubber which is designed for highly efficient gas-liquid exchanges. The primary absorbent is a chromium salt which is oxidized, but reduced back by contact with amalgamated zinc.

The gas stream may flow at any rate up to 20 l/h and the reagents need only be renewed at long intervals. The two purifiers, which comprise the system, will also retain impurities such as CO_2, H_2S, SO_2, Cl_2, NH_3 and amines.

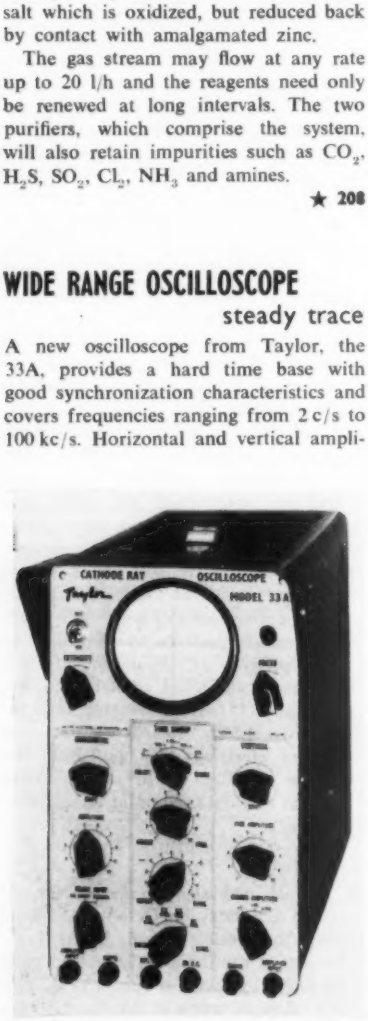
★ 208

WIDE RANGE OSCILLOSCOPE

steady trace

A new oscilloscope from Taylor, the 33A, provides a hard time base with good synchronization characteristics and covers frequencies ranging from 2 c/s to 100 kc/s. Horizontal and vertical amplifiers with push-pull output are provided; the latter has a high gain and a frequency range extending from a few cycles per second to 60 Mc/s. Both amplifiers have outputs corresponding to several screen diameters, thereby making it possible to examine all kinds of wave forms, including pulse types of short duration, and also to extend them for detailed examination.

★ 209



The 33A oscilloscope has a stabilized power supply giving a steady trace Range is from a few cycles per second to 60 Mc/s

CORROSIVES CONDENSER

new graphite element

Powell Duffryn have recently added to their range of 'Delanium' graphite heat exchange equipment a new graphite cartridge condenser, specifically designed to solve a wide range of condensing problems involving corrosive vapours.

The graphite element is cylindrical in form and is equipped with through holes along the major axes down which the condensing vapour passes. The service fluid passes in counter-flow through the annular space between a steel jacket and the slotted outer surface of the graphite cartridge.

If service fluids other than water are employed the steel jacket may be lined with suitable inert materials.

The new condenser is being manufactured in a range of sizes from 4 to 90 sq ft and above.

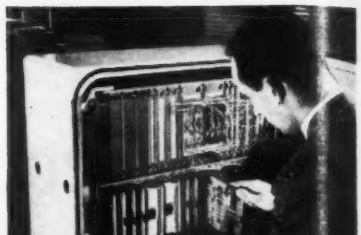
★ 210

ANALOGUE COMPUTER

on-line process control

As a possible alternative to the larger digital equipment that is being used for process control, De Havilland Propellers have introduced the Anatrol analogue system. The analogy to the various quantities for control appear in terms of d.c. voltages and these are manipulated by the computer to an accuracy of ± 1·0% of full scale. The input signals and the transmitted control signals which are in analogue form, match the signals transmitted and accepted by normal plant instruments. The need for analogue/digital and digital/analogue converters is thus eliminated.

Anatrol employs a modular form of construction, so that only those units required for a particular control problem need to be incorporated. It makes use of a time-shared computing system in which a minimum of mathematical units, usually one multiplier and three amplifiers, is brought into operation repeatedly during a calculation sequence by a 25-position switch which moves at the rate of one step each second.



The lower part of the Anatrol analogue computer houses the arithmetic unit into which a printed circuit card is being inserted. The upper half contains the patching array by which the arithmetic unit is sequentially connected

The mathematics are solved by the units in a series of steps which are controlled by the switch, and the results of each step are stored until they are brought into the sequence again or fed to control units on the plant. Depending upon how many steps are necessary for the solution of the equations, fresh levels of control signals are fed to the plant every few seconds. The longest period between the setting of fresh values is 25 seconds, this being the full capacity of the computer.

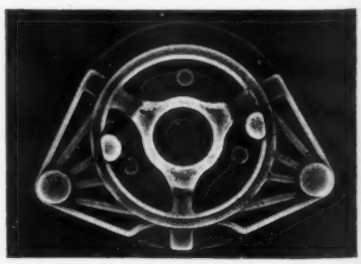
Anatrol can receive up to 42 input signals and can transmit 6 output signals. If necessary, more than one computer may be used at the same time; each can communicate with the other to form one large unit. The use of the 25-position switch has the effect of making 25 times as many amplifiers and multipliers available for any given problem.

★ 211

INDUSTRIAL RADIOGRAPHY

xerography applied

Rank Xerox have developed a process that applies xerography to X-ray work. Using commercially available equipment, marketed by Watson, an industrial X-ray



This xeroradiograph of a casting shows a resolution that compares favourably with medium speed non-screen industrial X-ray film

picture can be developed in 15 seconds. Its applications include the inspection of light alloy castings, hidden structures, assemblies, potted circuits and welds.

Image contrast is accentuated at sharp boundaries and for small details such as cracks and pinholes. The overall contrast is, however, low and a large thickness range can be accommodated in one exposure, a feature that can lead to economy in the number of radiographs necessary for a given examination.

The sensitive element detecting the X-ray image is a thin layer of photo-conducting selenium on a metal backing plate. This plate is sensitized by giving the selenium surface a uniform electrical charge. On exposure, using conventional X-ray apparatus, the selenium conducts charge to the backing plate by an amount depending on the X-ray intensity. An electrical image is produced on the selenium surface and it is made visible by blowing charged powder against the selenium. A built-in 35 mm camera is used to make a permanent record of the image.

The plate which has a sensitive area of 13 in. × 8½ in. can be used again; its average life is about 1000 exposures.

★ 212

IRRADIATION UNITS

cobalt-60 facilities

Nuclear Engineering Ltd, in association with the Hawker Siddeley Nuclear Power Co, are making available revised versions of their cobalt-60 irradiation units, the Automatron H/1, with a 50,000 curie source, for use in an irradiation cell, and the Automatron T2, a self-contained unit utilizing a 10,000 curies source.

Type H/1 has been constructed in the form of a block with a work table top, the latter consisting of a thick steel plate coated with stainless steel sufficiently robust to take heavy equipment requiring irradiation, under a wide range of physical conditions.

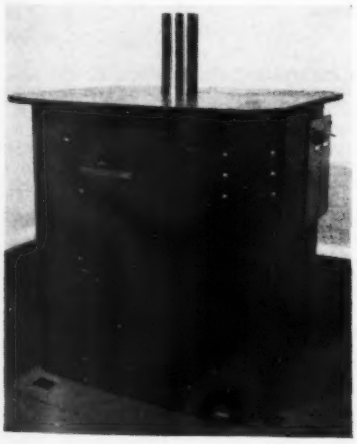
The source pencil, a stainless steel tube capable of accepting an encapsulated source of maximum length 10 in. and a maximum active diameter of 0·8 in., is located in the central channel of the transportable inner container, a cylindrical drum filled with lead. This is further surrounded by a solid cylindrical iron ring.

The source pencil is raised and lowered by means of a push rod and the design is such that movement between shielded and fully exposed positions takes only 1½ seconds. A stainless steel jig mounted at the centre of the working table protects the raised source pencil against mechanical damage.

Type T2, which can be erected in any convenient position, weighs some 22,000 lb and is essentially a cylindrical composite block of heavy metal, lead and steel containing the source holder, and an outer static shield carrying a lead-filled protective lid.

The source holder is so constructed that two irradiation fields are provided, one of which is within the source-holder itself. The inner field, to which access is obtained from either above, when the protective lid is removed, or through a longitudinal slot in the source jig, provides a dose-rate in air of about 2·5 million rad/h. The outer field, with an annular space of 10 in. high and inner and outer diameters of 5·1 in. and 13·8 in. respectively, provides, at the outer edge of the field, a minimum dose-rate of some 500,000 rad/h.

★ 213



The cobalt-60 H/1 kilocurie irradiation unit, showing the key operated safety time delay interlock panel and the steel jig that protects the source pencil

ACCELERATORS

industrial units

To meet the need for higher power and economic industrial irradiation facilities, Radiation Dynamics are manufacturing a line of accelerators, the Dynamitron, for both electron and positive ion application, covering the range: 1·5 MeV 15 kW and 3 MeV 30 kW, with a 45 kW in development. The main characteristics are constant potential, a large current output and rugged construction.

The constant potential power supply converts low voltage a.c. power to high voltage d.c. power by means of a cascaded rectifier system driven in parallel from a 300 kc r.f. oscillator. The rectifier tubes, which are connected in series between ground and the high voltage terminal, are positioned in two columns on opposite sides of the acceleration tube.

The assembled high voltage elements, the beam tube, the rectifiers and the corona shields are positioned between a pair of large semi-cylindrical electrodes which form the tuning capacitance of an LC resonant circuit. The entire apparatus is enclosed in a grounded pressure vessel, filled with sulphur hexafluoride gas at high pressure to prevent sparking and corona discharge.

In the Dynamitron, the corona rings which enclose the beam tube and rectifiers, serve to suppress sparks and corona discharge and provide a large surface capacitance for coupling r.f. power to rectifier

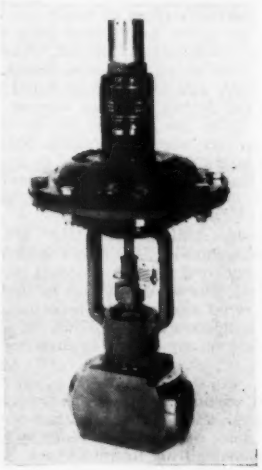
By operating at radio frequencies, no large capacitors are required to store energy between cycles and to smooth output. Accidental spark breakdowns are therefore not violent and there is no risk of damage to the rectifier beam tube.

★ 214

DIAPHRAGM VALVES

semi-corrosive use

For operation in a wide variety of semi-corrosive media, British Arca have introduced the Uniflow 800 series of Bar-



The Uniflow diaphragm valve is available in sizes from ¼ in. to 1 in. and for pressures up to 60,000 lb/in²

stock diaphragm operated valves, of direct or reverse acting type.

Standard body pressure ratings are steel 15,000 lb/in², and brass 800 lb/in². Special bodies for 60,000 lb/in² rating, with high pressure tube connexions, can also be supplied.

The flow range is 50–1 and the flow control in valve travel is governed by the shape of the grooves, milled or ground, in the plug surface.

The valve seats, which are removable, are screwed into the body and are precision lapped to ensure a tight shut-off.

★ 215

STEAM RAISING ON SITE

compact oil burner

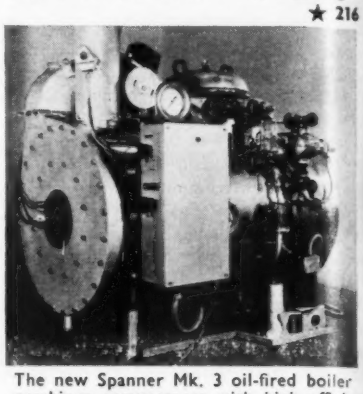
Extreme smallness leading to very low radiation losses is a feature of the recently introduced Spanner Mark 3 boiler. It is basically a return tube economic type designed so that the furnace is completely concentric with the boiler shell, thereby reducing uneven stresses to a minimum.

The pressure jet oil burner used has been designed to give a very short but highly radiant flame so that the maximum heat is taken from the flame through the furnace walls, leaving a smaller proportion of the heat to be taken out by the Spanner 'Swirlyflo' tubes.

This particular design, combined with the fact that pre-heated combustion air is used, enables the boiler to give efficiencies of up to 84%. Ease in overhaul and maintenance is an additional feature.

Boilers of the Mark 3 type are available for outputs ranging from 500 lb/h to 10,000 lb/h, the 1000 lb/h boiler having overall dimensions of 5 ft 4 in. long × 3 ft 3 in. wide × 4 ft 3 in. high.

★ 216



The new Spanner Mk. 3 oil-fired boiler combines compactness with high efficiency. This model, which raises 2500 lb/hr of steam, is 5 ft 8 in. long × 4 ft 2 in. wide × 5 ft 6 in. high

IN BRIEF

• **Oscillograph recorder.** A new direct-writing oscillograph from Savage and Parsons records at frequencies from d.c. to 1000 c.p.s. and above, and provides a choice of eight paper speeds, from 5 in./min to 150 in./s. It gives a well defined trace at writing speeds in excess of 12,000 in./s.

★ 217

• **Solenoid valve.** For use in flow systems as an on/off control where the maximum flow rate is 525 ml/min at 60 cm head of water, Griffin and George have introduced the Grundy valve, a cylindrical glass plunger, actuated by a concentric solenoid from a mains control unit.

★ 218

• **Minute filter.** A filter, that is effective down to about one-thousandth of a micron, capable of filtering any particle which can be seen with the electron microscope, has been developed by the Kent Floor Machine Co. Fitted in a mobile industrial vacuum machine, it permits an air flow of 150 c.f.m. from a 1 h.p. motor.

★ 219

• **CO_2 valves.** A range of small gas valves for nuclear power plants have been developed by Teddington Controls. Available either as cap sealed or bellows sealed, they include both gate (wedge) valves and globe valves. The former, in sizes ranging from 2 in. to 12 in., are intended for infrequent operation and where emergency operation will not arise; the latter, from ½ in. to 4 in., are for frequent or emergency operation.

★ 220

• **Electronics testing.** 'Zero-Mist' available from Livingston, is a useful aid in detecting faulty capacitors, resistors, soldered joints or transistors. Sprayed directly on to the component, rapid evaporation lowers the component temperature and allows immediate observation of any change in characteristics.

★ 221

• **Metal coatings.** A new high-temperature torch, suitable for applying coatings of high melting point or reactive material by spraying, is available from British Oxygen. Materials successfully deposited include zirconia, alumina and titania; tungsten, tantalum and silicon; titanium and stainless steel; and tungsten carbide and nickel-chromium-boron alloys.

★ 222

• **Clean conditions.** Dust barrier curtaining manufactured by Anti-Dust Services has now been improved to render it inflammable and resistant to chemical change. Where no air filtration system exists, air passes through at slow, natural velocity rates.

★ 223

• **Water strainer.** Megator Pumps have introduced a floating suction strainer, for use with 6 in. hoses, that is capable of dealing with water flow rates of up to 750 gal/min. Made entirely of plastics and stainless steel, they are virtually immune from corrosion.

★ 224

• **Mobile pump.** A trailer version of the Sykes standard UVS2 Univac pump is now available. The output of the pump at 1500 r.p.m. is 8000 gal/h, at a total head from all causes of 20 ft, the output at 39 ft being 3000 gal/h.

★ 225

• **Oscilloscopes.** Research and Control are distributing two new oscilloscopes, type GM5606, designed for measurements between 0·200 kc/s (−3 db) with 10 mV/cm sensitivity, and type GM5601, covering the frequency range 0–5 Mc/s (rise time 75 musec) with 100 mV/cm sensitivity. Both time and voltage calibrations have an accuracy of ±3%.

★ 226

• **Storage oscilloscopes.** Cawkell's Trace Shifter, used in conjunction with transient storage oscilloscopes, such as the Remscope, is designed to allow display, in sequence, of up to ten signals coming from the same source. Each signal is displaced vertically relative to its predecessor so that comparison may be made.

★ 227

• **Semi-conductor devices.** Suited for applications in logic, switching and computer circuitry, where faster switching times than those possible with transistors are required, tunnel diodes have been developed by Westinghouse made of germanium crystal produced by a controlled dendritic growing process.

★ 228

• **Rotary control.** Plessey's have developed a unit that rotates a shaft to any one of twelve positions, each position being set up independently, with an accuracy of within 6 minutes of arc. It is available for 12–48 volt d.c. operation in two panel sizes (4 × 4 in. or 3¼ × 4¼ in.) and with a torque of either 35 oz-in. or 60 oz-in.

★ 229

• **High-pressure lubricant.** For use under excessive loads, heat and pressures, a lithium-based all-purpose grease, with a non-corrosive additive, is being distributed by Bardahl Products.

★ 230

• **Induction heaters.** Philips new range of h.f. induction heaters, 6, 12, 18 and 30 kW, can be interchanged so that each generator can be converted to high, medium or low impedance and high, medium and low kVA output.

★ 231

• **Impregnated dry bearings.** Birfield have improved their Polyslip p.t.f.e. bearings, thereby increasing their scope in terms of load, speed and life. The upper limit of operation is at about 280°C and the lowest down to −200°C.

★ 232

• **Temperature measurement.** Fielden's new electronic temperature indicator-controller is completely transistorized and can be operated from 12 volts d.c. or mains supply. Calibrated for temperatures between −200°C and 850°C (in 73 standard ranges), the platinum resistance measuring bulb can be located at any distance up to 300 ft away from the instrument.

★ 233

★ For further information on any item circle the appropriate number on the reply card facing page 162.

Here Is Your Guide
TO THE SERVICES OF A
Complete Nuclear Fuel Facility

	Cladding Materials Al Nb SS Be Zr	Pellets in Tubing SS Zr Al	Fuel and Fuel Alloys U-Zr U-Nb U-Al U-Mo U,Th	Fuel Dispersions and Ceramics UC UO_2-SS U_3O_8-Al UO_2 in graphite ThO_2 in graphite	Control Materials B-Al B-SS B_4C-Zr Hf
PRODUCTS					
Castings	√		√		
Clad Materials	√		√	√	√
Control Rods					√
Dispersions				√	√
Fabricated Assemblies	√	√	√	√	√
Fabricated Shapes	√		√	√	√
Foil	√		√		√
Fuel Elements	√	√	√	√	
Fuel Rods		√	√	√	
Poison Strips					√
Tubing	√				
Wire	√		√	√	
PRODUCTION SERVICES					
Annealing and Heat Treating	√		√		√
Assembly	√	√	√	√	√
Brazing	√	√	√		
Casting	√		√		
Cladding	√	√	√		√
Chemical Milling	√		√		√
Extrusion	√		√		
Machining	√	√	√	√	√
Materials Research	√	√	√	√	√
Rolling	√		√	√	√
Vapor Blasting	√		√	√	√
Welding	√	√	√		√
TESTING SERVICES					
Autoclaving	√	√	√	√	√
Chemical Analysis	√	√	√	√	√
Isotopic Analysis			√	√	
Metallography	√	√	√	√	√
Non-Destructive Testing	√	√	√	√	√

A CHECK LIST OF M & C NUCLEAR'S PRODUCT, SERVICE AND TESTING CAPABILITIES

These product, service and testing capabilities are backed by our wide experience in the nuclear field, our skilled technicians and our specialized equipment. We will be glad to work with you at an early stage in your project planning to make suggestions that may result in important economies.

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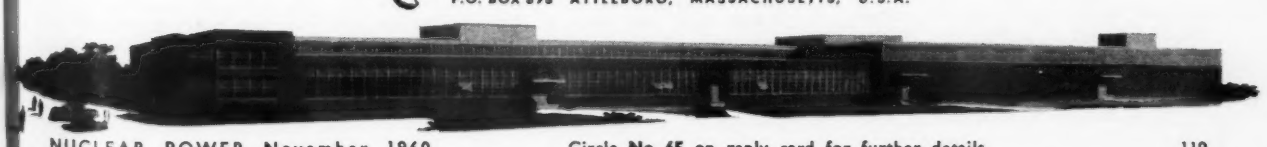


BUSINESS NEWS

GEC/ENGLISH ELECTRIC MERGER Persistent market rumours that the *GEC* was considering a link-up with another company have now been proved correct with the announcement that the *GEC* and *English Electric* are considering a merger. The plan is to form a holding company—whose assets might well be £M180—but the details are being worked out though another announcement is expected shortly. When it comes about, the merger will make the new electrical group one of the largest in the world and may well reduce the number of nuclear consortia in this country from the original five to two. However, according to a GEC spokesman, it will take some months before any further decisions are taken. The GEC has assets of about £M87 and employs 70,000 persons while English Electric has assets of some £M89 and about 84,000 employees. Each had a trading profit of some £M11 last year. The two concerns overlap in the fields of heavy engineering, domestic appliances, lighting, telecommunications and nuclear power. In addition, English Electric has large aviation interests while the GEC manufactures radio and television sets.

Meanwhile, the earlier link-up between the *GEC-Simon Carves Atomic Energy Group* and *Atomic Power Constructions* has now been formally completed with the formation of the new firm, *United Power Company*. (See *Nuclear Power*, September, p 130.)

ERICSSON/BENDIX AGREEMENT Agreement in principle has been reached with the *Bendix Corporation* and *Ericsson Telephones Ltd* on the formation of a jointly owned company in the UK to manufacture and market a wide range of high precision instruments and electronic devices for industrial and scientific requirements. Bendix was recently involved in a deal with City bankers who have bought its holdings in *Elliott-Automation*.

AMF AND UK RESEARCH REACTORS A major assault on the market for training and research reactors in the UK is to be made by *AMF Limited* of London, a member of the *American Machine & Foundry Co. International Group*. Mr. Frank X. White, vice-president of *AMF International*, estimates the market at about 12 reactors while Mr Gordon Jackson, chairman of AMF Ltd. and manager of the Nuclear Power Division of Mitchell Engineering, says 'We are entering the field of research reactors and it is hoped that we will gain the same pre-eminence here as our American company which has erected 10 reactors and is building a further 11'. *Nuclear Power* understands that negotiations are proceeding with a Glasgow tender for a research reactor (see *Students*, p. 110) AMF, who have moved into new London headquarters in Savile Row, are also to establish a laboratory in Berkshire for research in chemistry, physics and electronics.

BERKELEY EQUIPMENT CONTRACT *Teleflex Products Ltd* of Basildon are to supply 60 sets of damper gear each for the two reactors for the Berkeley Nuclear Power Station. In addition, Teleflex are supplying window gear control for the reactor physics block and workshop and maintenance block for the second reactor building, Zero 2, at the AEA Establishment at Winfrith Heath.

• The X-ray scanning microanalyser developed by *Tube Investments Research Laboratories* and the *Cavendish Laboratory* (see *Business*, August, p 108) is being manufactured and marketed under licence from TI Ltd, by the *Cambridge Instrument Co. Ltd.*

OVERSEAS

ISRAEL'S AGREEMENT WITH NUMEC. The Israeli Atomic Energy Commission has signed a co-operation agreement with Nuclear Materials and Equipment Corporation (NUMEC) of Pennsylvania. Under this, NUMEC will serve as technical consultant and training and consultant agency in the United States for the Israeli body. The agreement covers an initial term of five years and is one of a series of similar arrangements under negotiation by NUMEC with foreign government agencies and industrial groups. The firm's policy is to strengthen its international marketing position and assure up-to-date technical liaison in its field of nuclear materials development.

AEC CUTS COBALT-60 PRICES The USAEC has lowered its prices for cobalt-60 and established a new schedule of discounts for large quantity purchases. For all material in quantities greater than 100,000 curies a price of one dollar per curie has been set (this price does not include source selection, handling or shipping charges). Purchasers of cobalt-60 in quantities of 100,000 curies or more should write to the Director, Office of Isotope Development, USAEC, Washington 25.

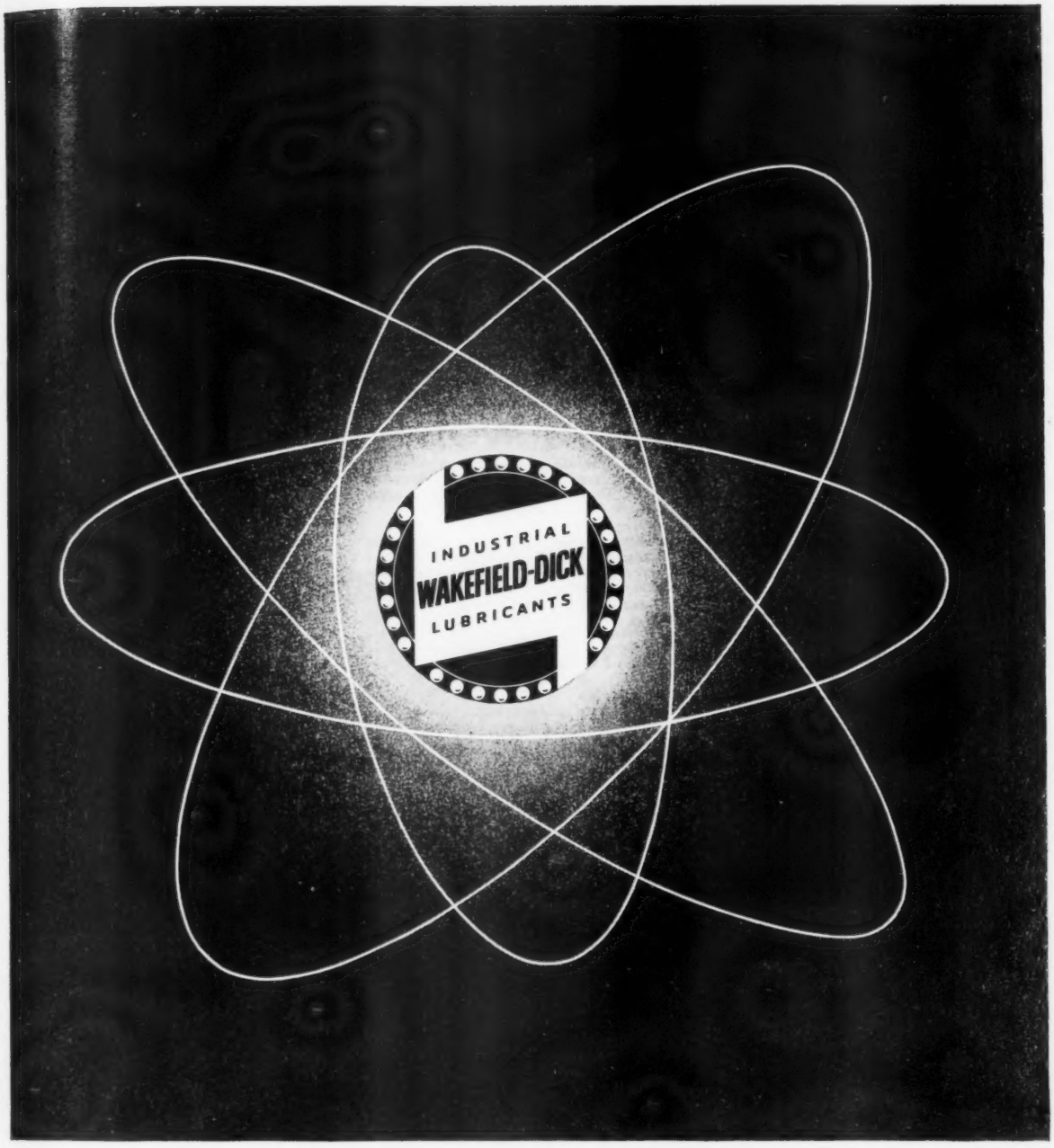
US REFUELLING MACHINE DESIGN Proposals have been invited by the AEC from US firms for the design, development and possible fabrication of a prototype on-power refuelling machine to be used in connection with pressure tube-type, heavy water moderated, natural uranium power reactors. The machine will permit the loading and unloading of reactor fuel elements in pressure tubes while the reactor is operating at full power. The firm selected will be required to complete the work within two years.

• *M & C Nuclear Inc*, a *Texas Instruments Inc* subsidiary, has a contract to supply 1600 prototype fuel elements for the *Allis-Chalmers* 66 MW boiling water 'Pathfinder' reactor being built for the Northern States Power Company.

• *Badische Anilin-und-Soda Fabrik AG* are to install a *Thompson Ramo Wooldridge* RW-300 Digital Control Computer this year. It will be the first closed-loop computer system installed outside the US.

• *Vitro Chemical Co.* of the US is cutting the price of scandium oxide by almost 50% —but in ultra-pure form, the cost is nearly £100 a lb.

The radiofrequency liner for the Rutherford High Energy Laboratory synchrotron starts on its journey from London Aluminium Co. Ltd's works. It is enclosed in Vybak (pvc) film made by Bakelite Ltd to keep dust out. (See Progress in Industry, this issue)



WAKEFIELD-DICK

NUCLEOL

RADIATION RESISTANT LUBRICANTS

chosen for Chapelcross, Berkeley and Dungeness

Wakefield-Dick Industrial Oils Ltd., Castrol House, Marylebone Road, London, N.W.1. A member of the Castrol Group of Companies

Diary

25 OCTOBER
Observations on the design and construction of the N.S. 'Savannah', London. Meeting of Joint Nuclear Propulsion Panel, The Institute of Marine Engineers, 76 Mark Lane, EC3

26–27 OCTOBER
Computer Applications symposium, Chicago. Details, Mr A. Ungar, Armour Research, 10 W. 35th St., New York 13.

31 OCTOBER
The Application of Irradiation in Industry, Liverpool. Branch meeting, The Institution of Electrical Engineers

31 OCTOBER—2 NOVEMBER
13th Annual Conference on *Electrical Techniques in Medicine and Biology*, Washington. Details, Dr Robert L. Bowman, National Heart Institute, National Institute of Health, Bethesda 14, Md, USA

1–3 NOVEMBER
Use of welding in chemical plant in the AEA, Autumn meeting, Institute of Welding, London

8 NOVEMBER
Some contributions from nuclear power to engineering, Institution of Civil Engineers discussion, London

7–11 NOVEMBER
IAEA Seminar on Nuclear Energy, San Carlos de Bariloche, Argentina

14–18 NOVEMBER
IAEA *Nuclear Ship Propulsion and Safety* Symposium, Taormina, Sicily

21–25 NOVEMBER
Second Industrial Photographic & Television Exhibition at Earls Court, London, SW5

24–25 NOVEMBER
Meeting of the American Physical Society, Chicago, Illinois

28 NOVEMBER—9 DECEMBER
IAEA Regional library workshop on *literature in the field of nuclear energy*, Manila

29 NOVEMBER
Nuclear Temperature Scanning Symposium, The Society of Instrument Technology, London. Details, 20 Queen Anne Street, London, W1

29 NOVEMBER—2 DECEMBER
Corrosion and Metal Finishing Exhibition, Empire Hall, Olympia, London. Details, 9 Eden Street, London, NW1

30 NOVEMBER—2 DECEMBER
Steels for Nuclear Reactor Pressure Circuits Iron and Steel Institute at Hoare Memorial Hall, Church House, Great Smith Street, London, SW1

Future months

4–9 DECEMBER
Annual meeting, Radiological Society of North America, Cincinnati

5–9 DECEMBER
IAEA Symposium on *Pest Control by Radiation*, India

6 DECEMBER
Welding processes, design of pressure vessels, etc, Birmingham meeting organized by the British Welding Research Association

7 DECEMBER
Recent developments in the welding of pressure vessels, Dr H. Harris, Glasgow. Details, The Institute of Marine Engineers, 76 Mark Lane, London, EC3

7 DECEMBER
Dounreay Fast Reactor Symposium (arranged under aegis of British Nuclear Energy Conference), Institution of Mechanical Engineers, London, SW1

11–14 DECEMBER
Eighth Hot Laboratory and Equipment Conference, San Francisco. Details, James R. Lilienthal, Los Alamos Scientific Laboratory, P.O. Box 1663, Los Alamos, New Mexico

12–15 DECEMBER
1960 *Western Atomic Fair*, jointly sponsored by the American Nuclear Society and Atomic Industrial Forum, San Fransico. Details, Exhib Mgr., AIF, East 54th Street, New York 22

15–16 DECEMBER
Autumn meeting, Powder Metallurgy Joint Group, includes symposium on *practical aspects of pressing metal powders*, Church House, Great Smith Street, London, SW1

DECEMBER (date later)
Sixteenth Session, European Council for Nuclear Research, Geneva. Details, ECNR, Geneva 23, Switzerland

1961

3–9 JANUARY
48th session of Indian Science Congress. Details, General Secretary, 64 Dilkhusa Street, Calcutta 17

16–19 JANUARY
Automation conference and exhibition, Instrument Society of America, St. Louis, Missouri

16–22 JANUARY
Physical Society exhibition. Details from 1 Lowther Gardens, Prince Consort Road, London, SW7

28 FEBRUARY
Safety of Nuclear Marine Propulsion Plant, joint panel, J. M. Murray and H. Pemberton, organized by The Institute of Marine Engineers, 76 Mark Lane, London, EC3

15 MARCH
Burst Slug Detection Symposium, London. Details, The Society of Instrument Technology, 20 Queen Anne Street, London, W1

21–26 MARCH
Electrical Engineers Exhibition, Earls Court. Details, Electrical Engineers A.S.E.E. Exhibition Ltd, Museum House, Museum Street, London, WC1

5–7 APRIL
Electrical Contacts Symposium, London. Details, The Secretary, The Institute of Physics and The Physical Society, 47 Belgrave Square, London, SW1

20 APRIL—4 MAY
Engineering, Marine, Welding and Nuclear Energy Exhibition, Olympia, London. Details, S. W. Bridges & Sons Ltd, Grand Buildings, Trafalgar Square, London, WC2

APRIL (date later)
Seventh Nuclear Congress, Chicago. Details, Engineers Joint Council, 29th West 39th Street, New York 18

11–15 JUNE
British Electrical Power Convention, Eastbourne

Industrial Literature

Electronic instruments. Pye's latest catalogue of scientific instruments describes briefly their range of galvanometers, potentiometers, resistance bridges and boxes, magnetic instruments and measuring microscopes.

★ 247

Heating equipment. A new catalogue from Electrothermal describes a wide range of heating equipment for laboratory and industrial usage.

★ 248

Electrical instruments. New catalogue sheets from Muirhead cover the D-930-A a.c. voltmeter with a range of 1 mV to 300 V, and the K-100-A automatic recording wave analyser. The latter has a frequency range of 10 c/s to 19 kc/s and an amplitude range of 10 mV to 300 V.

★ 249

Electronic components. A wide range of small sized components is described in Ardente's 1960 catalogue and includes potentiometers, transformers, chokes and switches.

★ 250

Induction heating. Redifon's 'News Letter' introduces a new range of medium- and low-power induction heaters that have output powers ranging from 1 kW to 12 kW.

★ 251

Electron beam heating. The current 'Wild Barfield Heat-Treatment Journal' describes the principles behind the use of electron beams for melting, purifying and welding metal.

★ 252

Voltage stabilizers. A catalogue from English Electric, covering their range of tubes for stable output voltage, includes electrical and mechanical data.

★ 253

Automatic handling. A system that directs remotely controlled manipulators by analogue control has been announced in a leaflet from General Mills.

★ 254

Stress relief. The many applications of coiled or finger elements for preheat and stress relief are detailed in a handbook published by Cooper Electroheat.

★ 255

Flow indicators. A leaflet from Rotameter describes the new type 715 range of small flow indicators for panel mounting, intended for use with air and non-corrosive gases.

★ 256

High pressure valves. A line of small forged bonnetless globe valves, primarily designed for extreme temperatures and pressures, are introduced in Newman Hender's publication 315.

★ 257

Speed Reducers. Varatio Strateline Gears have recently issued technical data sheets covering their speed reducer series. These units are obtainable in single, double or triple stage form and are claimed to give twice the output for the same sized gearbox.

★ 258

Reactor physics. The current 'Fairey Review' continues Mr Duncton's atomic energy series by discussing control of the fusion process. Another article describes a filter unit that can be used equally as well for gases and tar.

★ 259

Scanning recorder. Suitable for thermocouples, strain gauges and other applications, the 'In-line' scanning recorder, described in a recent Cambridge leaflet, is designed to select and scan from 20 up to 400 points, recording each point sequentially.

★ 260

Welding alloys. A useful guide to the properties and techniques of over 150 eutectic low temperature welding alloys and fluxes is now available from Eutectic Welding Alloys.

★ 261

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Sir Roger Makins (left) AEA chairman and chief UK delegate, at the fourth IAEA General Conference at which 71 member states were represented. On his left is Mr M. I. Michaels, Under-Secretary, Office of the Minister of Science

People

by John Radford

AN AUSTRALIAN, I note, is the new chairman of the IAEA Board of Governors. He is **Mr Allan D. McKnight,** 42 year old executive commissioner of the Australian AEC and a former lecturer in law at Canberra University College. Backing him are **Professor G. Nadjakov** of Bulgaria and **Dr Carlos Graef Fernandez** of Mexico who are the new vice-chairmen. The Board also appointed a scientific advisory council whose members include **Dr Isidor Rabi** of the US, **Prof. W. B. Lewis** of Canada (a contributor this month to the *Viewpoints* page), **Prof. Louis Cintra do Prado** of Brazil and **Sir John Cockcroft.**

ALLAN McKNIGHT
IAEA chairman

GORDON JACKSON
joins AMF

Sir John, incidentally, recently returned from Hungary where he was the guest of the Hungarian Atomic Energy Commission and the Presidium of the Hungarian Academy of Sciences. While there, he visited research establishments and delivered a lecture. One of the likely results of his trip, I understand, is the interchange of scientists for long or short periods. Next on the list for Sir John is a trip to Dalhousie University, Canada, to receive an honorary degree after which he will be attending a meeting of the UNO and the International Atomic Energy Commission Scientific Advisory Council as a delegate.

In their move to capture a large share of the market for research reactors, AMF Limited have appointed **Mr Gordon Jackson** as chairman of the board of directors. Before joining AMF, Mr Jackson was manager of the Nuclear Power Division of Mitchell Engineering and he told me that he was retaining this appointment to provide for continuing co-operation between the two companies in the nuclear field. This appointment and that of **Major-General G. D. G. Hayman** and **Mr G. M. R. Lord** as joint managing directors, said **Mr Frank X. White,** vice-president of AMF International, was in line with plans for a programme of continued integration and expansion in Britain.

The new head of the Department of Applied Physics at the new Lanchester College of Technology, Coventry, is **Dr F. J. Pearson** whom I met when he was at the Birmingham College of Advanced Technology.

Expansion seems to be in the air these days and the latest firm to announce new appointments as part of its drive forward is British Geon Ltd., a company in Distillers Plastics Group. Promotion within the group comes to **Mr A. H. Fletcher** and **Mr H. A. Wardle,** who have been appointed sales managers of Geon PVC resins and lattices and Hycar nitrile rubbers and acrylates respectively.

Growth again has been a factor in the appointment of **Mr J. R. Erskine** of Aveley Electric Ltd. He will direct sales of all Allen B. Dumont products for which the company have been agents since early this year. Mr Erskine will be responsible for the introduction of the new Digital Readout Oscilloscope 425. He was formerly design engineer of the company's Toroid Division.

A leading authority in the fields of chemical kinetics, statistical mechanics, energy transfer and molecular spectroscopy—**Dr K. E. Schuler**—has been appointed consultant to the Director of the National Bureau of Standards. He will serve as scientific adviser to the Director in connexion with the Bureau's efforts to strengthen its basic science programme. Dr Schuler, who was born in Nuremberg, Germany, is 38 years of age.

KURT SCHULER
basic science

WILLIAM DAY
managing director

I notice with some interest that **Mr William L. Day** has joined the Board of Landis & Gyr Ltd of North Acton and is now their managing director. He was chief nuclear project engineer and subsequently a partner with W. S. Atkins & Partners and one of the first engineers to enter the nuclear engineering field at the AEA's Industrial Group at Risley. He was there special assistant to the group managing director.

The US-French company, Dynatom, is gradually taking shape with the latest step being the appointment of the chief executives in the persons of **Vice-Admiral D'Escadre Joseph-Auguste Leurin,** as president and **Roger Julia** as vice-president. Named to the board of directors are **J. L. Atwood** and a well-known figure, **Dr Chauncey Starr,** president and vice-president of North American Aviation Inc. respectively. Dynatom, a joint Atomics International, Société Alsacienne de Constructions Mécaniques and Chantiers de L'Atlantique (Penhoet-Loire) concern, will build and market power and research reactors developed by Atomics International in France and the French Union.

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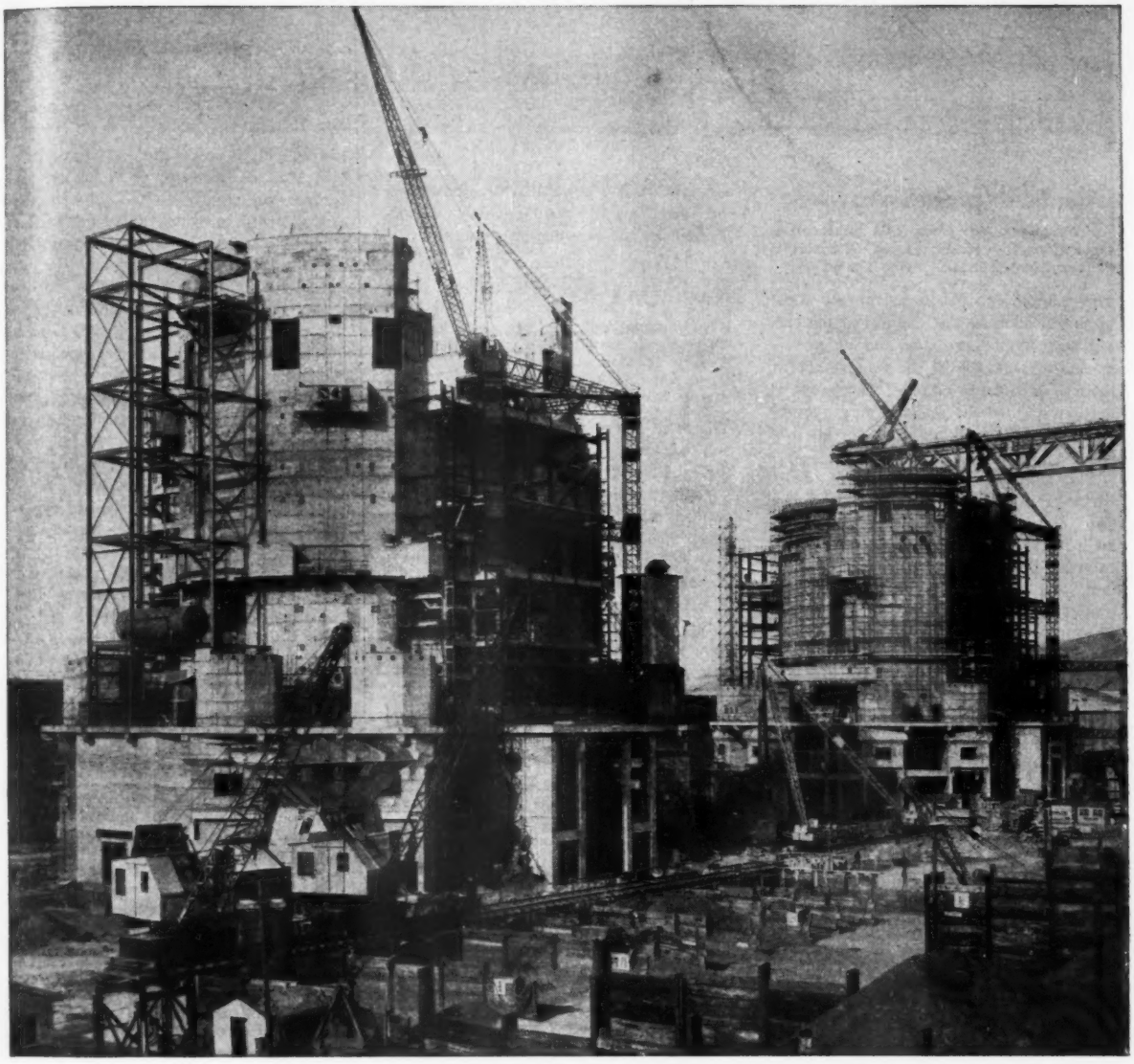

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Book Reviews

Chemical processing

Fundamentals of Chemical Engineering Operations, by M. G. Larian Constable, London 1960 656 pp Price 62s 6d

The author sets out to cover the most important elements of chemical engineering operations concisely and at undergraduate level. Whilst the importance of theory is acknowledged, the book is written so that the student may acquire sufficient practical knowledge for his first job.

The first section of the book deals with general principles and includes fluid flow, heat transfer, evaporation, mass transfer, the operating and mass transfer characteristics of phase contactors, and simultaneous heat and mass transfer. The second section discusses the separation of mixtures by interphase mass transfer operation and deals with the drying of solids, distillation and the special techniques employed, liquid–liquid extraction, solid–liquid extraction and gas absorption. The third section, on mechanical separation of heterogeneous mixtures, covers gravitational and centrifugal methods and filtration.

On the whole the book seems to be a little too elementary for undergraduate chemical engineering courses in this country. For example the chapter on special techniques in distillation is purely descriptive. Without being lengthened it could have indicated a method for designing extractive distillation columns or have included a discussion of multicomponent distillation. Again the section on heat conduction does not even mention transient flow.

Although parts of the book could have been more thorough, some particularly good sections are included such as the one on humidification and dehumidification. That it is up to date is shown by the discussion of the effect of surface active agents on mass transfer.

There are many worked examples besides set questions at the end of each chapter and the line diagrams and figures are very clear. Most of the references are taken from American journals. Only the occasional slip can be detected in these and the book as a whole is free from obvious errors.

Whilst there are several other books on chemical engineering, this textbook will be welcomed by students requiring an introduction to the basic principles of the subject. It will have to be supplemented, however, by more advanced works if used by honours degree students.

S. Hartland

Radiation hazards

Recommendations of the International Commission on Radiological Protection. Report of Committee II on Permissible Dose for Internal Radiation, 1959, Pergamon Press 233 pp Price 30s

The most recent recommendations of the International Commission on Radiological Protection are essential to anyone concerned with Health Physics, since protective measures in all countries are based on them.

For the average, practising, Health Physicist, much of the text and several of the tables will be of academic interest only; for example, the methods of calculation of maximum permissible exposure values are principally the concern of those carrying out research in this field. However, Table 1, giving maximum permissible body burdens and maximum permissible concentrations in air and water for occupational exposure to over 200 radionuclides, will be used extensively by radiation protection officers. In the interests of simplifying the application to occupationally exposed persons, concentrations are now given for exposure at the rate of 40 h/week and at 168 h/week, whereas previous recommendations only quoted values for continuous exposure.

The inclusion of two new tables is to be welcomed; Tables 3 and 4 give the maximum permissible concentrations of unidentified radionuclides in water and air respectively, for continuous occupational exposure. In these, by excluding a relatively small group of radionuclides, a single value is given. For example, the maximum permissible concentration in air is covered by 6 values, varying from $4 \times 10^{-13} \mu c/cm^3$, when no analysis of the air is made, to $10^{-9} \mu c/cm^3$, provided there are no α-emitters present and provided that eight β-emitters are absent. These two tables will fulfil the needs of most laboratories and, thus, avoid the necessity for reference to the much more complex Table 1.

It is probably inevitable, but none the less unfortunate, that there should be errors in a work of this type. However, the publishers provide an Errata sheet, giving corrections to be inserted on 15 pages, all but three occurring in the tables; it is important that these corrections should be made, since most of them require a reduction of the permissible values.

Hugh D. Evans

Harmful Effects of Ionising Radiations by Ethel Browning. 1959 Elsevier Publishing Co. 158 pp 300 refs. Price 15s

For nearly 20 years, the author has been HM Medical Inspector of Factories, concerned principally with the hazards arising from ionizing radiations and, in particular, with luminizing compounds containing radium. Understandably, the latter side is much in evidence, in this book, but it is not over-emphasized at the expense of other important aspects.

Although the book is written primarily for industrial medical officers, it should be readily understood by non-medical readers, who have interests in radiation protection.

The chapter on units and instruments is an excellent brief survey, covering all the vital points, though a more typical radiation monitor might have been chosen for the illustration.

Protective measures and subjects such as the transport of radioactive materials are described in sufficient detail for the reader to appreciate the problems involved, and there is a good survey of industrial uses of ionizing radiations.

The chapters on biological hazards take up rather more than half the book; they include discussion of acute, chronic and delayed effects resulting from external and internal radiation, and a fairly detailed review of the relationship between radiation and the incidence of leukaemia.

Hugh D. Evans

New books

- *Extractive and physical metallurgy of plutonium and its alloys* edited by W. D. Wilkinson Interscience, New York and London 1960 314 pp Price 79s ★ 262

- *Role of nuclear propulsion in merchant shipping* Atomic Industrial Forum, New York 1960 172 pp Price $7·50 ★ 263

- *Atomic and nuclear physics* by R. S. Shankland Macmillan, New York and London 1960 665 pp Price 49s ★ 264

- *International Symposium on High Temperature Technology—Proceedings* arranged by Stanford Research Institute, October, 1959 McGraw-Hill, New York and London 1960 384 pp Price £5 16s 6d ★ 265

- *Radioisotopes, a new tool for industry* by S. Jefferson Newnes, London 2nd edition, 1960 174 pp Price 21s ★ 266

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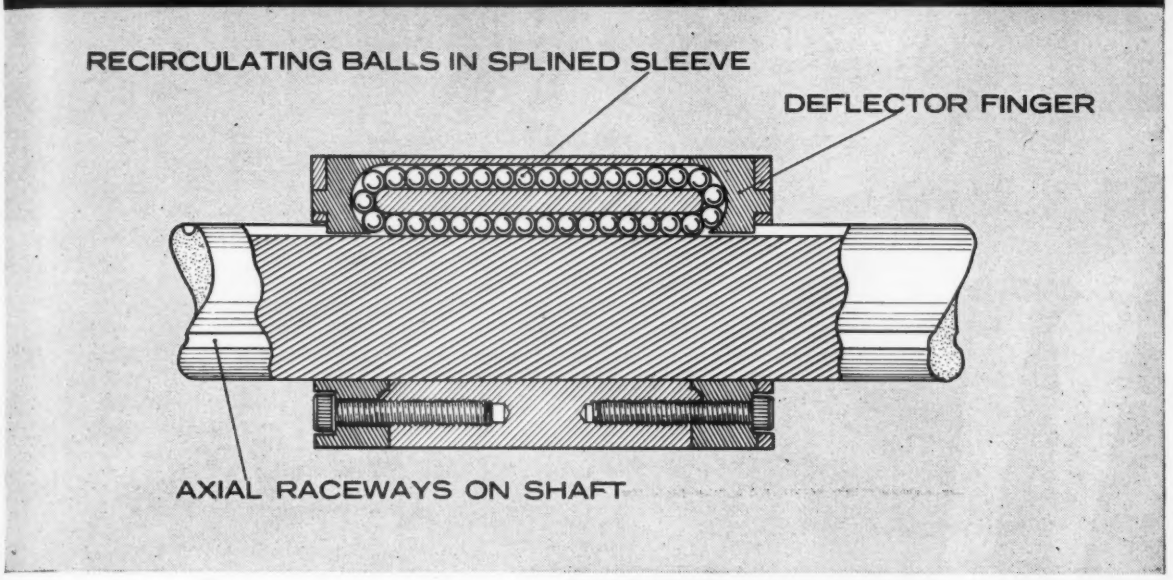

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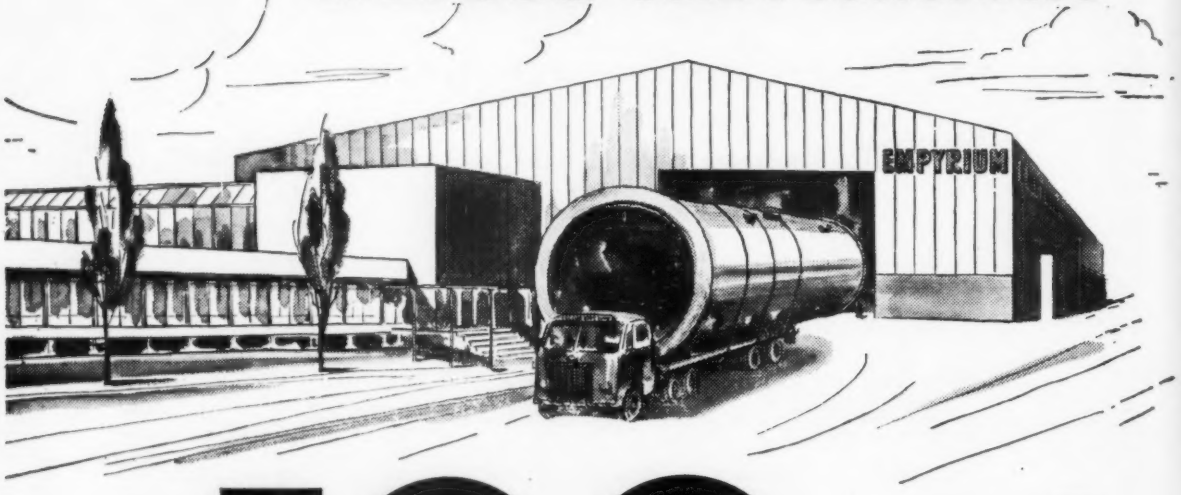

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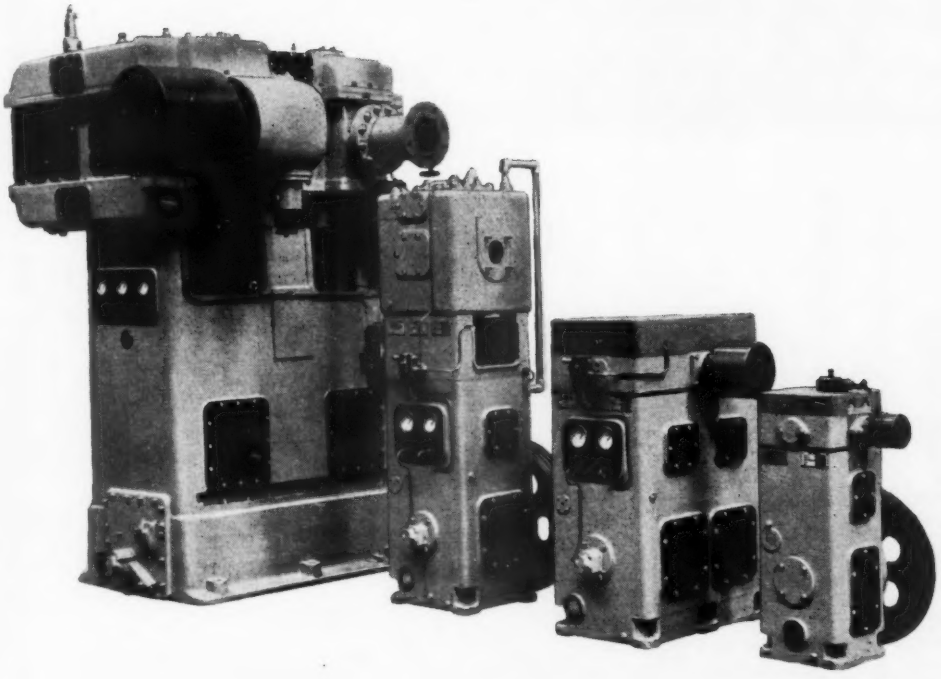

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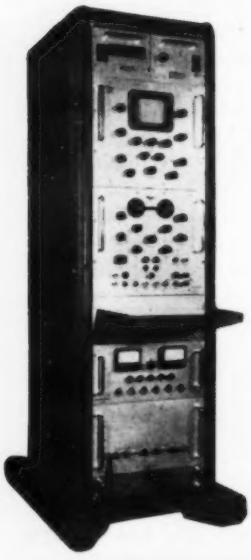

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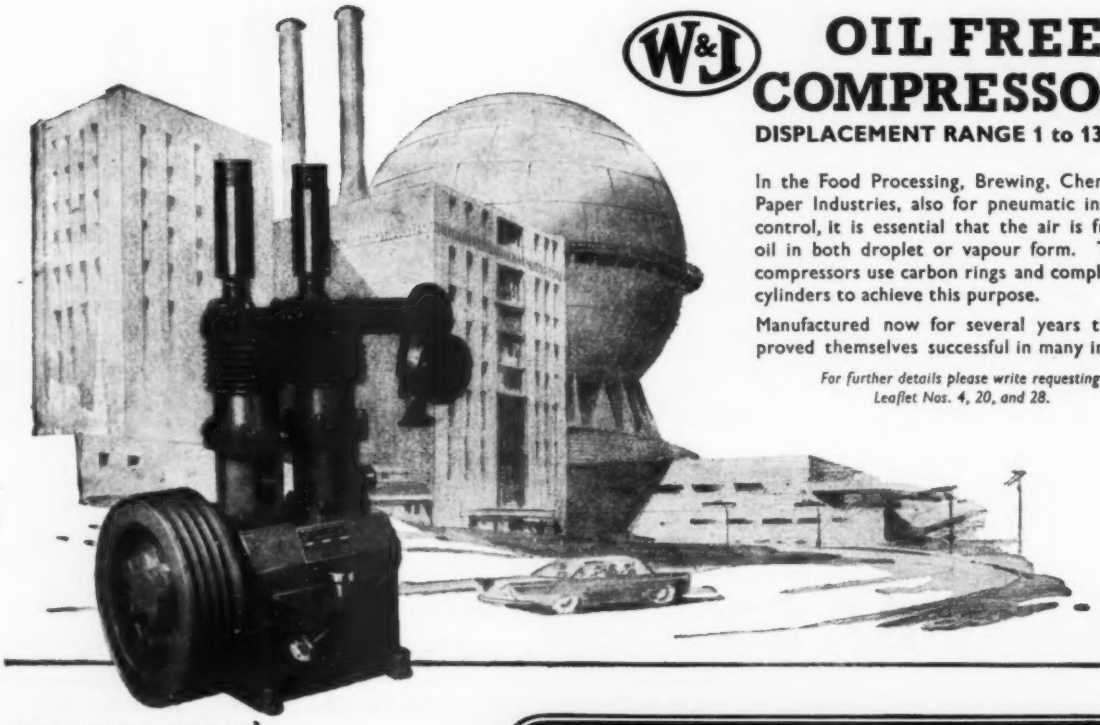

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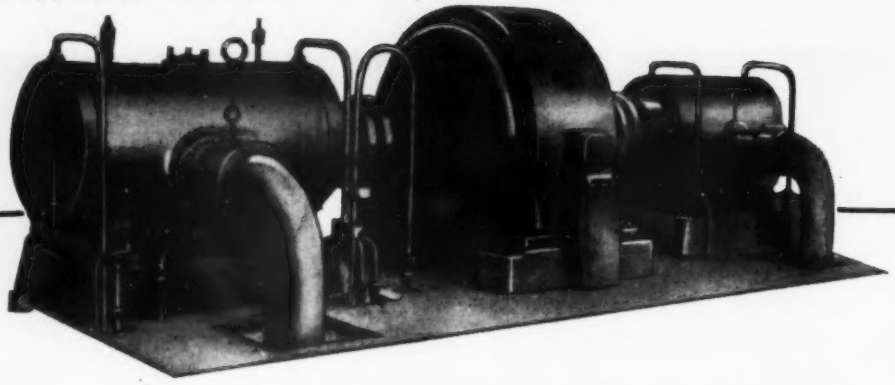

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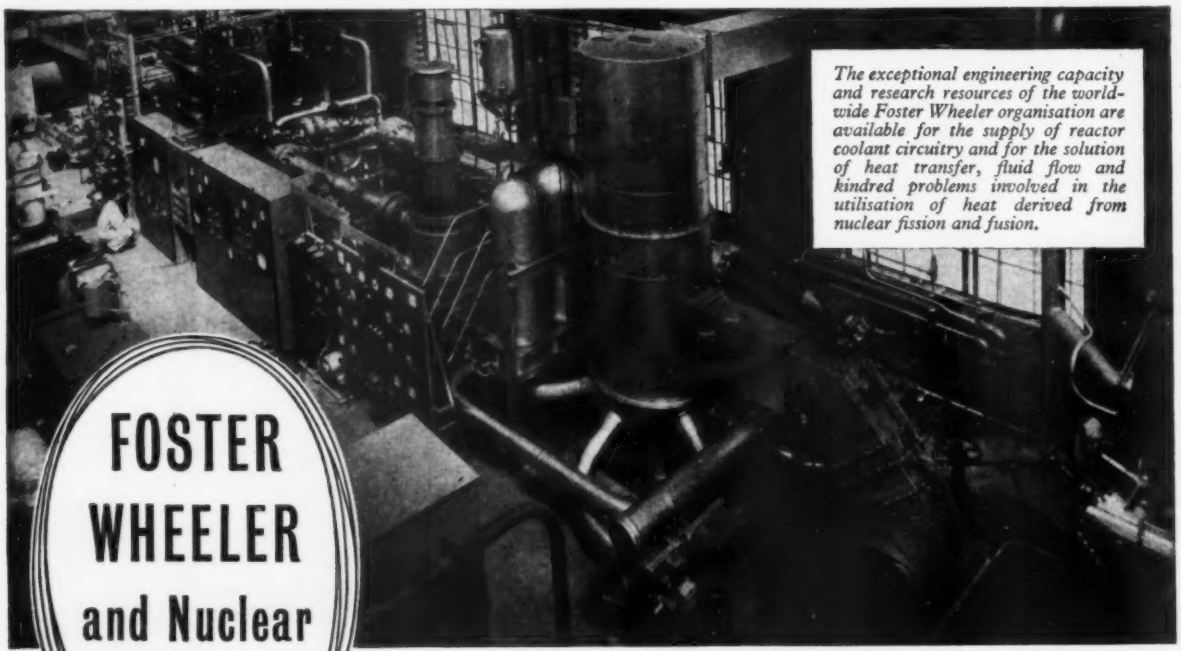

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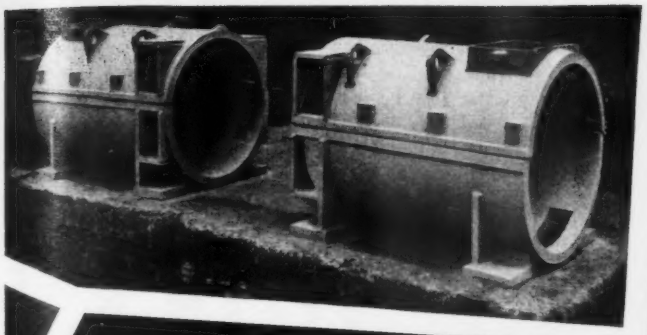

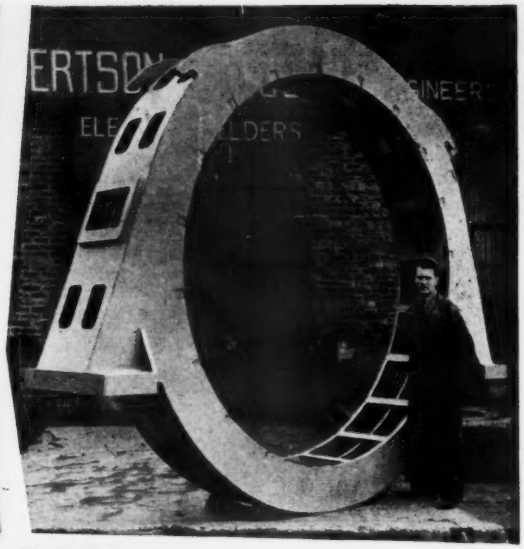

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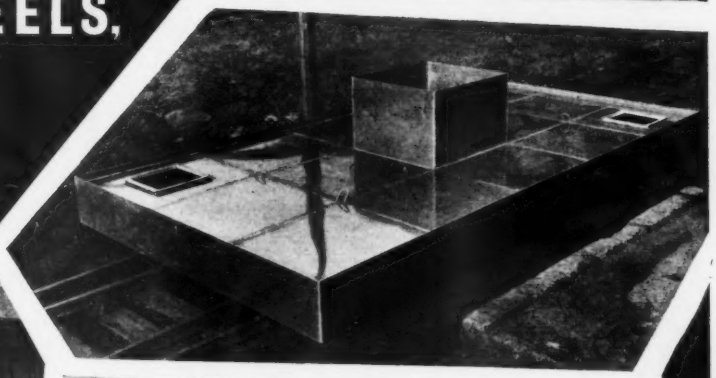

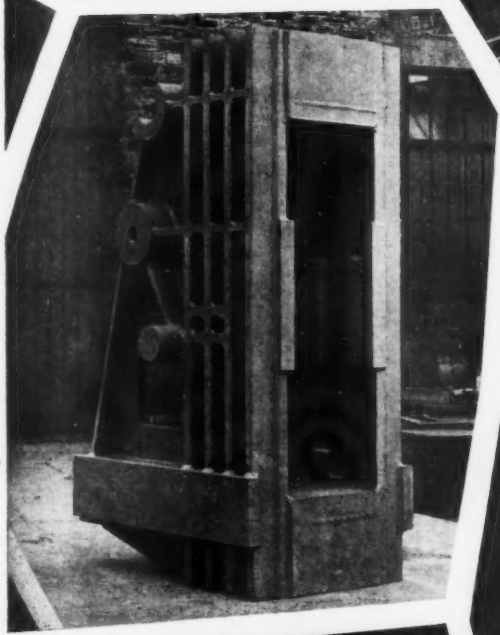

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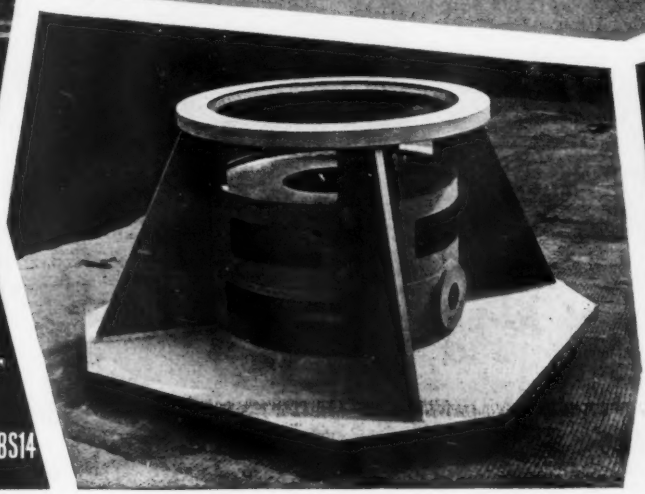

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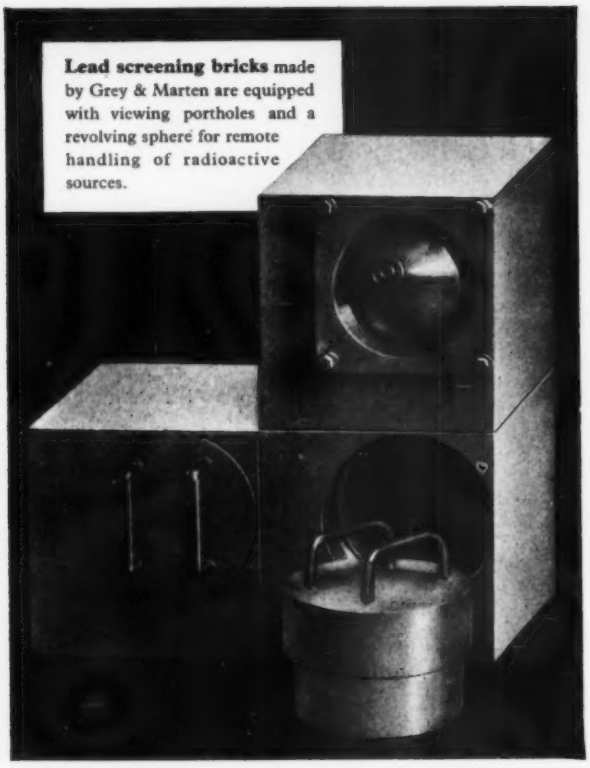

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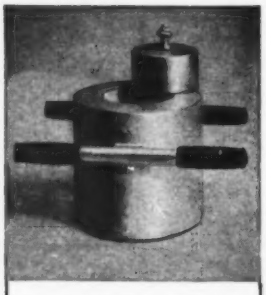

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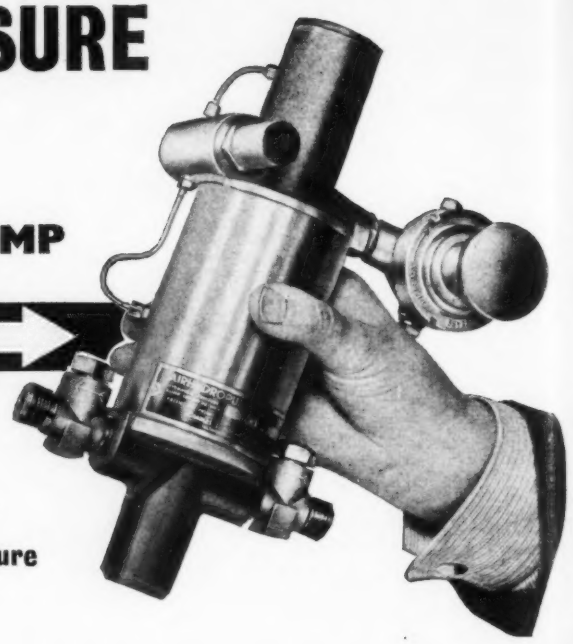

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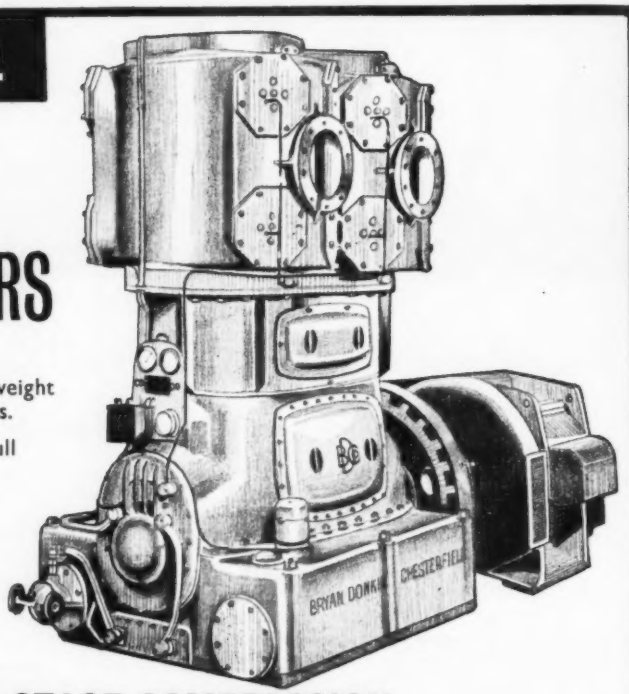
FOR AIR & GASES



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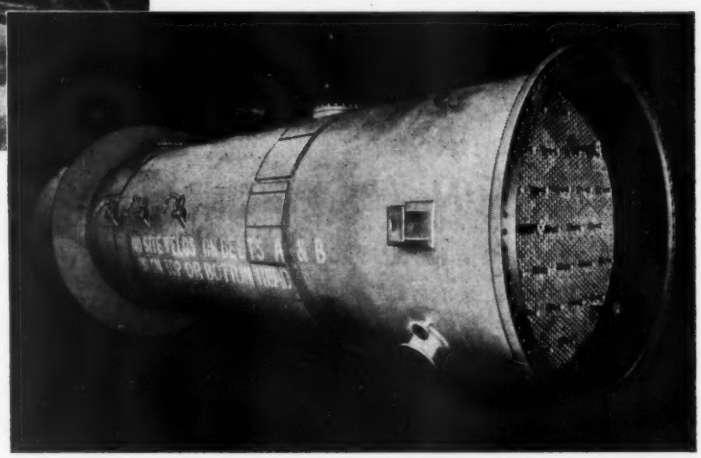

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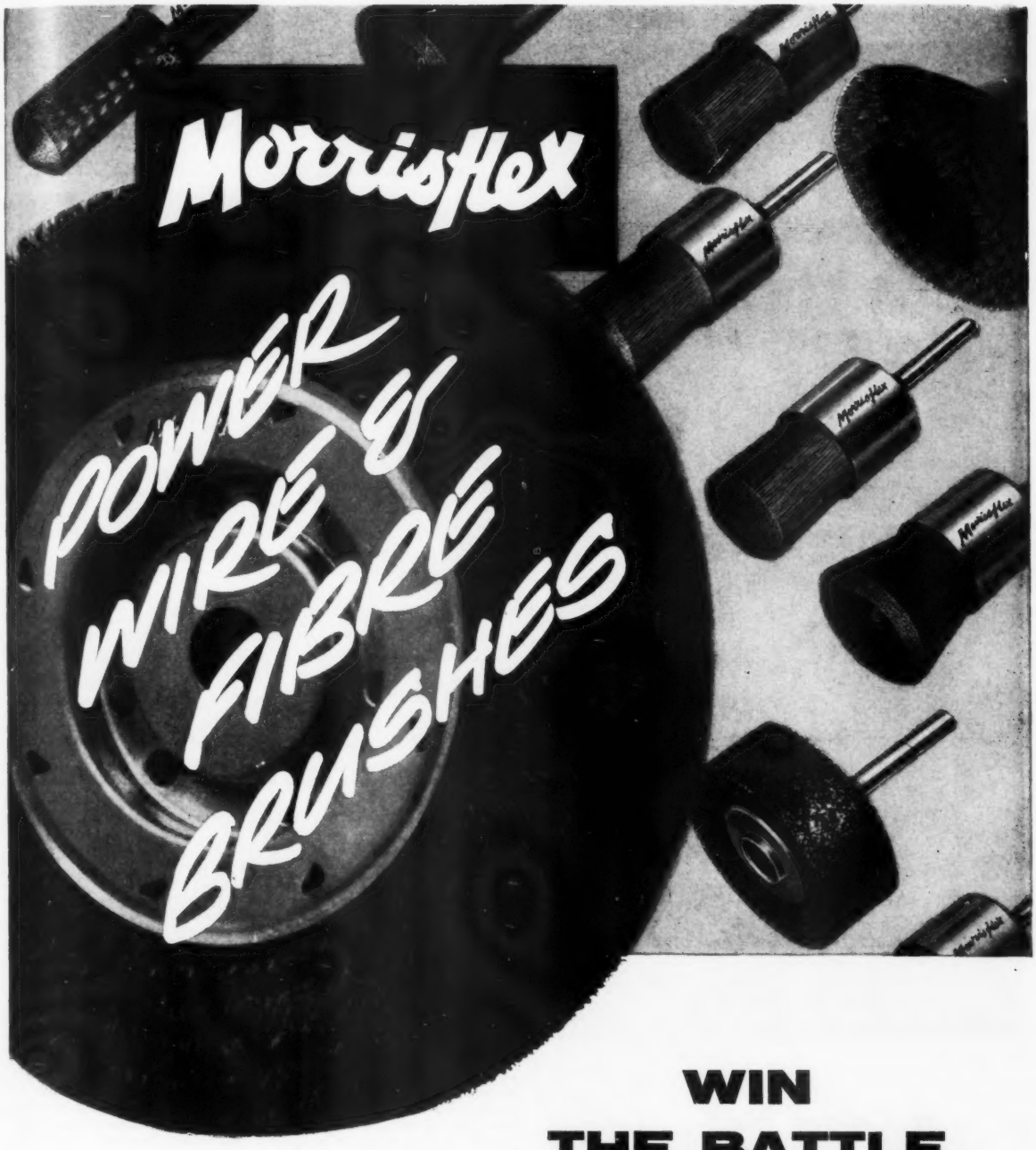

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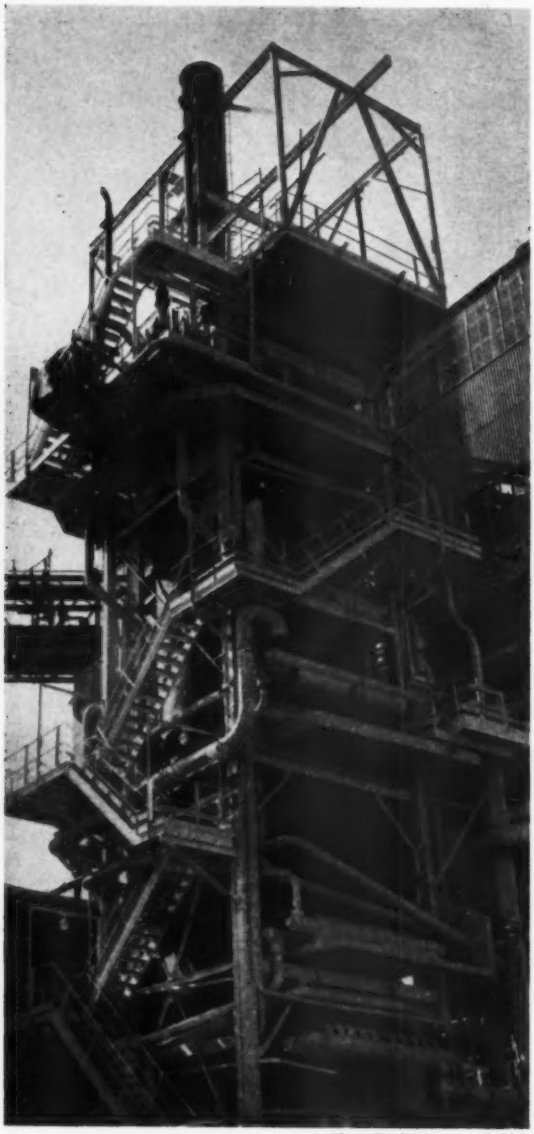

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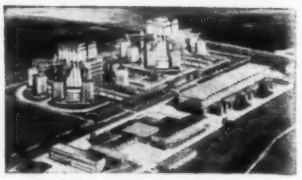

BERKELEY
(A.E.I.—John Thompson Nuclear Energy Co. Ltd.)

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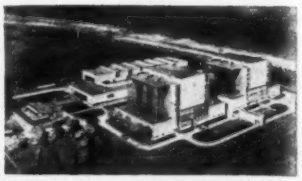

BRADWELL (The Nuclear Power Plant Company Ltd.)

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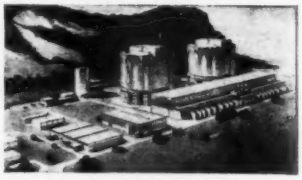

HUNTERSTON (G.E.C.—Simon-Carves Group)

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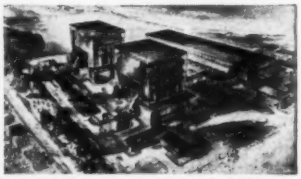

HINKLEY POINT (English Electric, Babcock & Wilcox, Taylor Woodrow Atomic Power Group)

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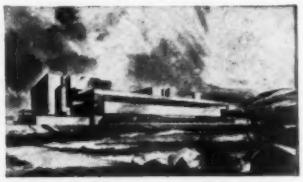

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(An impression by Mr. Basil Spence, Consultant Architect to Nuclear Civil Constructors, showing how the design blends into the landscape of Snowdonia)

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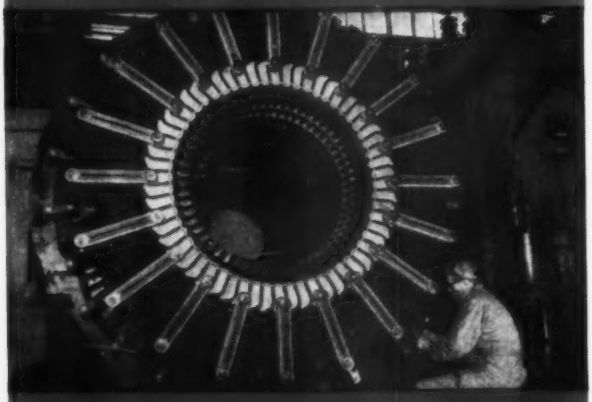

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- May be connected to follow meters in control room with inexpensive standard electric code wiring.
- Units are interchangeable without usual installation matching or calibration. Connectors may be used for quick connect and disconnect.
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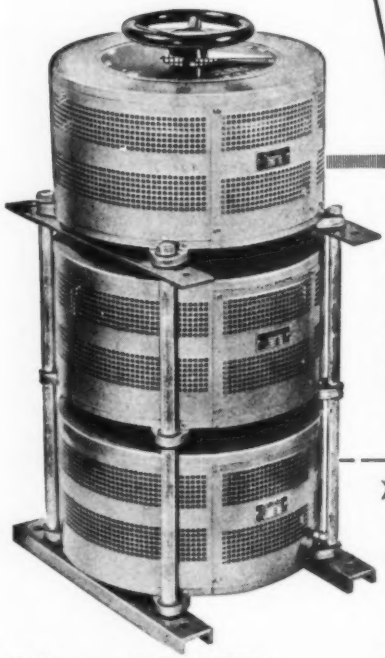

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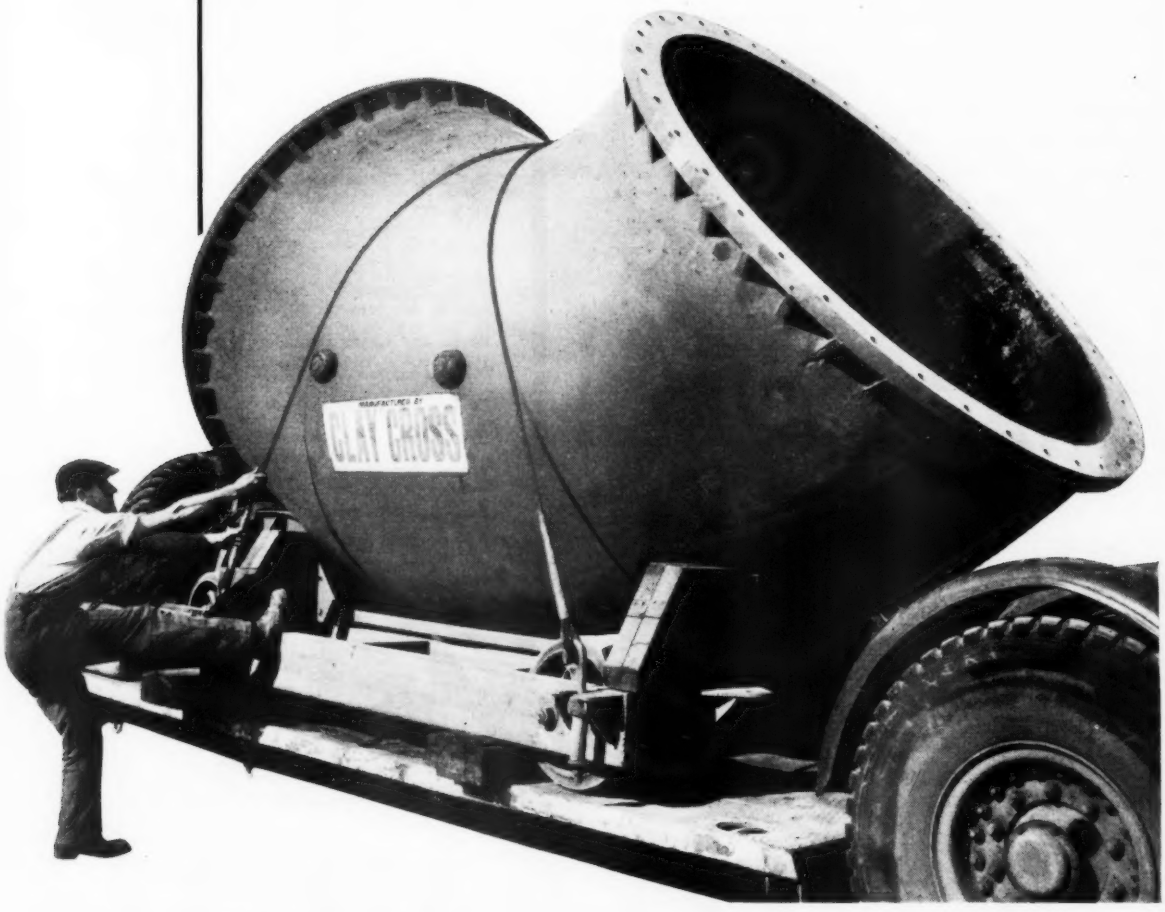

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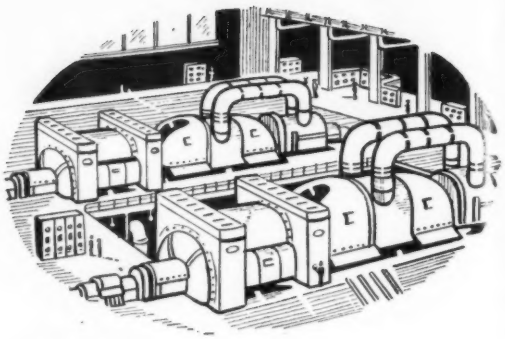

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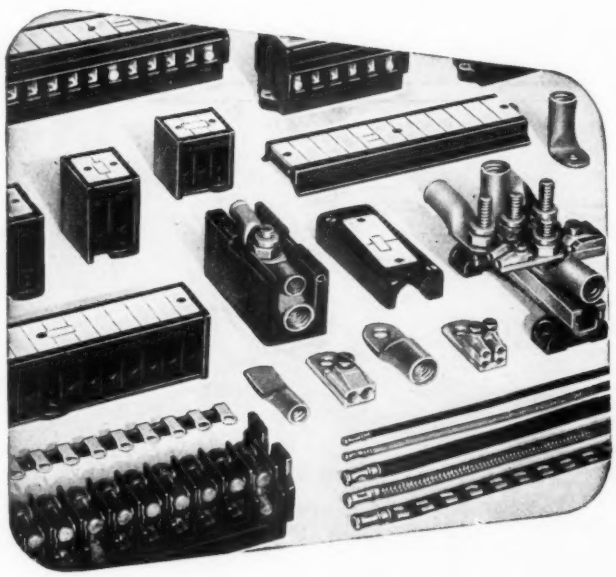

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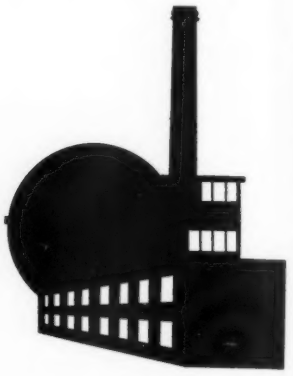

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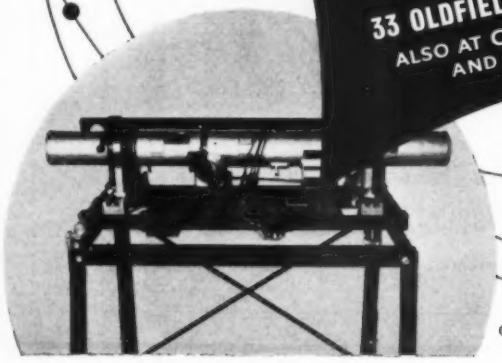

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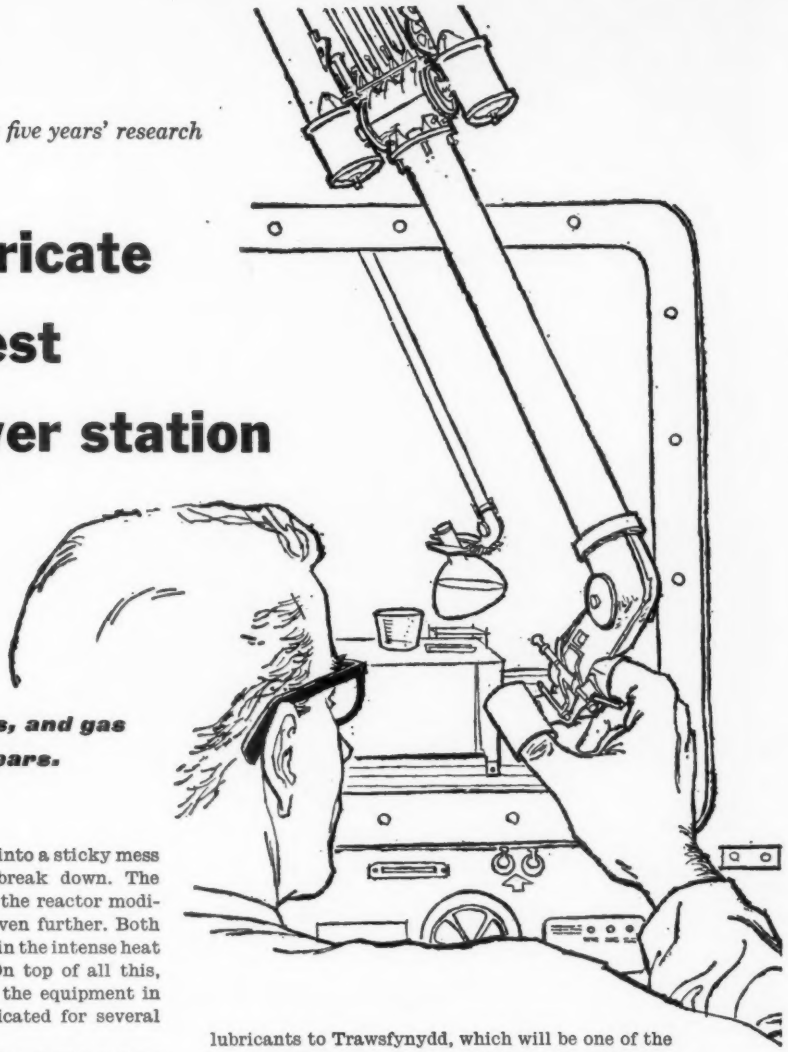
Trawsfynydd contract crowns five years' research

Esso to lubricate world's latest atomic power station



Intense research develops lubricants that resist radiation, high temperatures, and gas contamination for years.

Under radiation, normal oils turn into a sticky mess and ordinary grease starts to break down. The carbon-dioxide gas circulating in the reactor modifies the structure of the grease even further. Both lubricants break down completely in the intense heat surrounding a nuclear furnace. On top of all this, once the reactor has started up, the equipment in and around it cannot be re-lubricated for several years.

Now, after five and a half years' research, a team from the Abingdon Laboratories of Esso Research Ltd., has provided the answer.

Working closely with the scientists and engineers of the Central Electricity Generating Board's Atomic Power Division and the five consortia tendering for the new nuclear power station at Trawsfynydd, in Snowdonia, this team has developed a new range of lubricants, called Essotron oils and Cosmos greases, which are resistant to radiation, heat and gas.

And Esso have proved conclusively, in practical tests, that these lubricants will remain one hundred per cent reliable, even in the vital control machinery at Trawsfynydd, for the necessary length of time. As a result, the sole contract for the supply of all lubricants to Trawsfynydd, which will be one of the two biggest nuclear power stations in the world, has been awarded to Esso.

To the authorities concerned, however, this contract is much more than a reward for successful research. It is a means of ensuring that Esso's vast technical resources will always be available to study and meet the demands of the new reactor when it is in operation.

In other words, the C.E.G.B., the U.K.A.E.A. and Atomic Power Constructions Ltd., who have won the main Trawsfynydd contract, have proved, as hundreds of smaller organisations in less dramatic industries prove every year, that it pays not only to consult Esso, but to go on consulting them. If your firm has a lubrication problem this fact applies equally to you.

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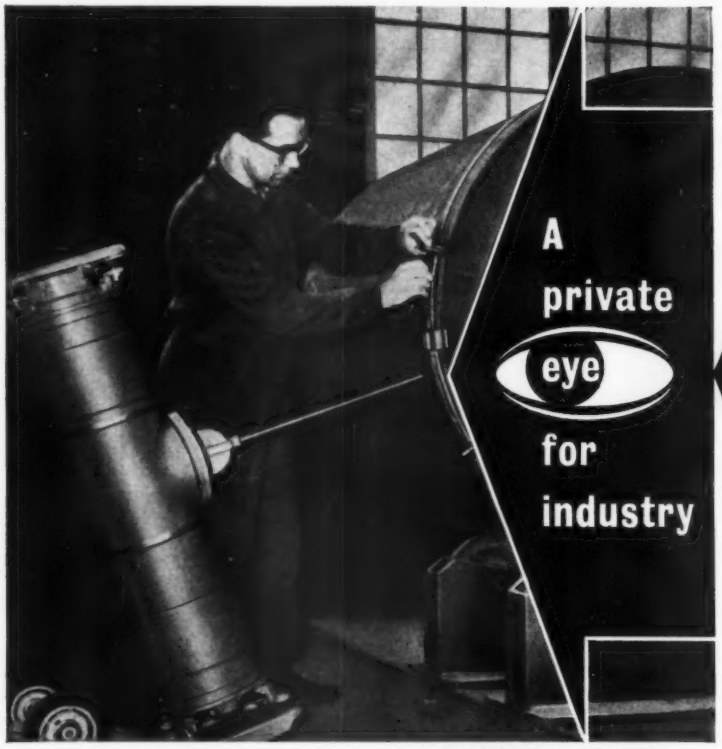

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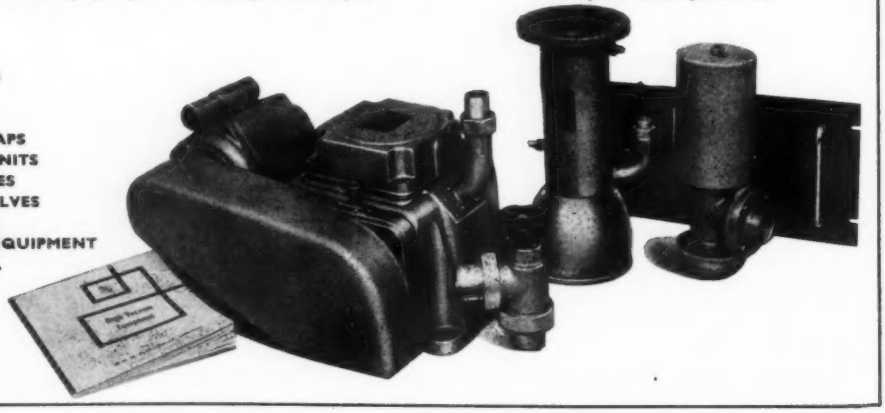

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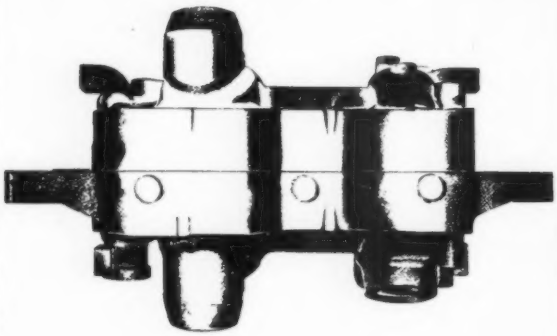

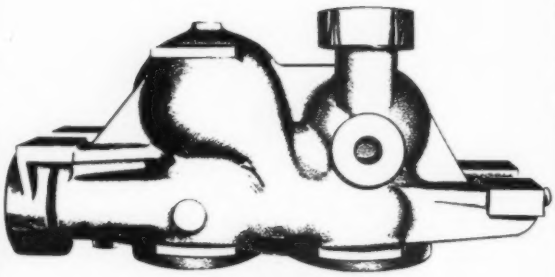

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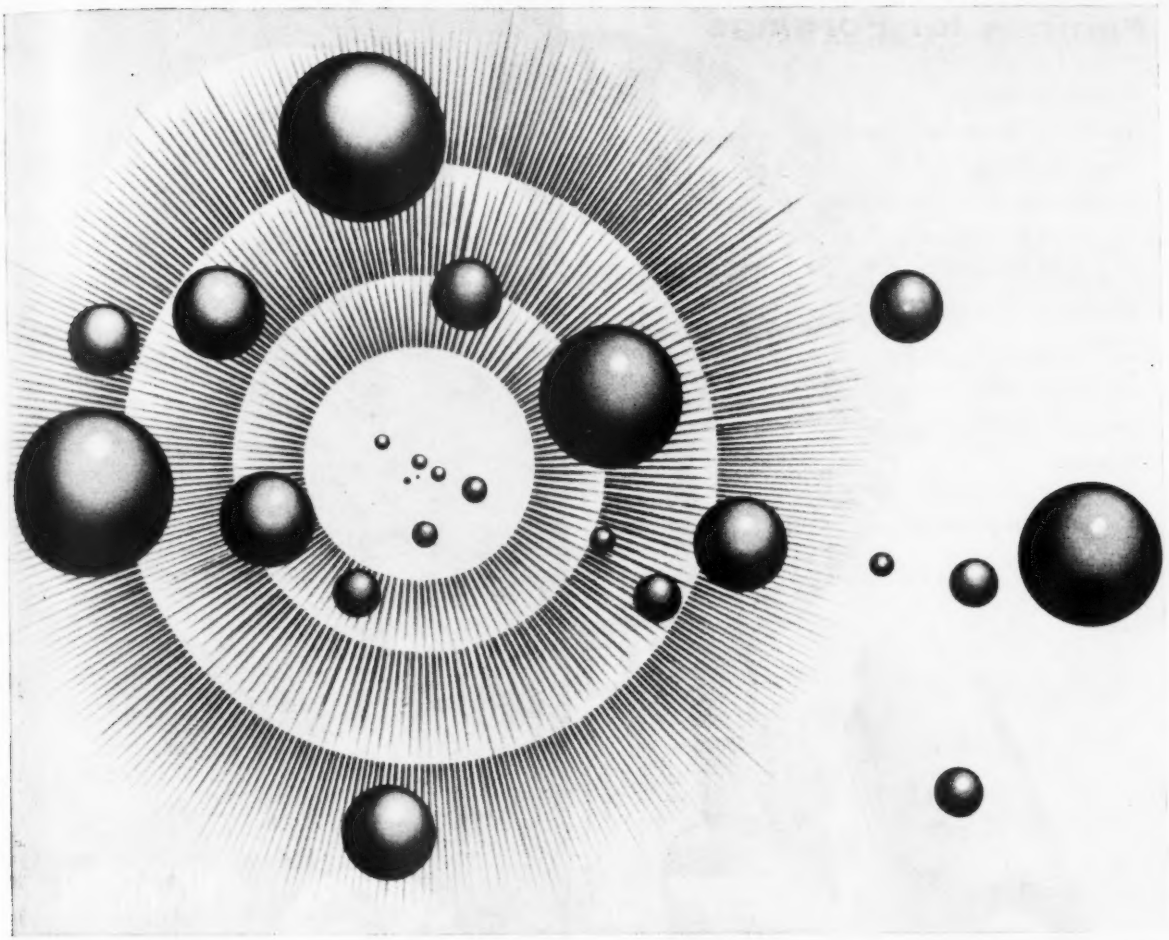

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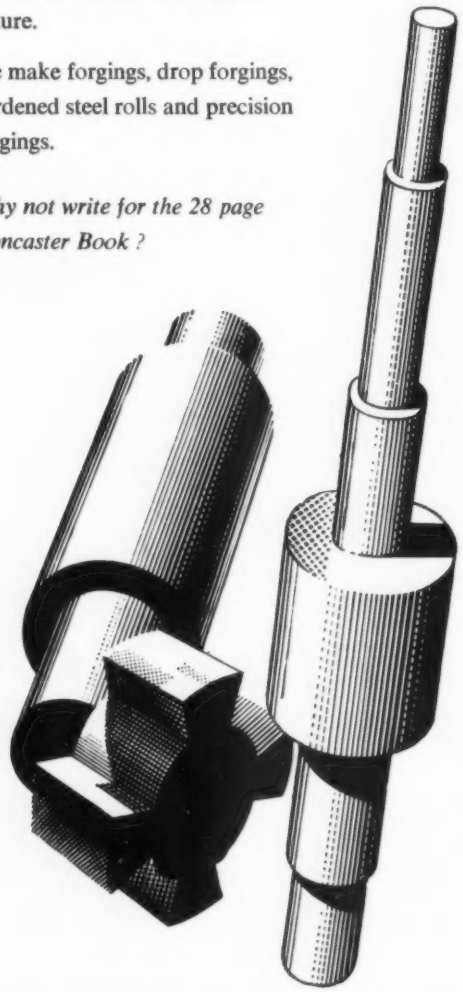

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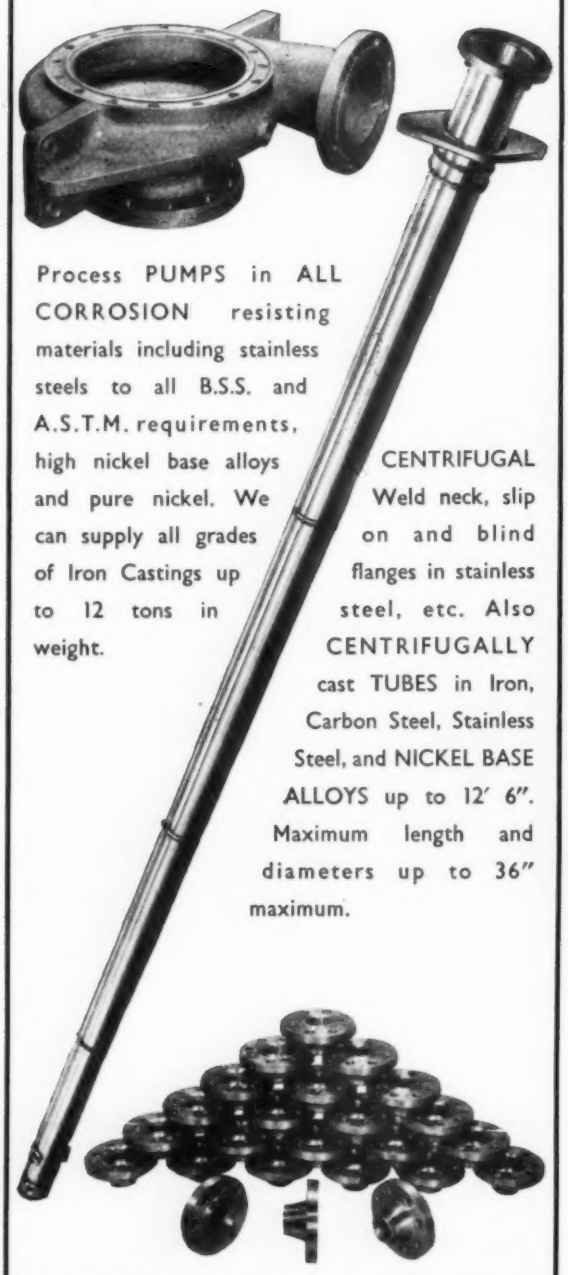

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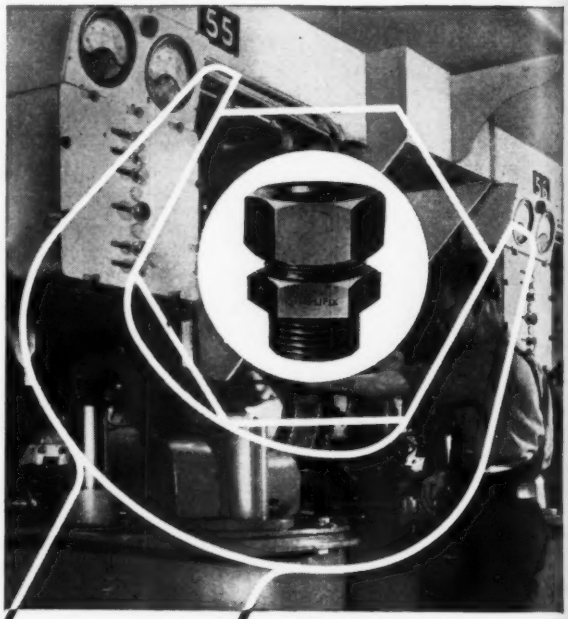

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7	30	53	76	99	122	145	168	191
8	31	54	77	100	123	146	169	192
9	32	55	78	101	124	147	170	193
10	33	56	79	102	125	148	171	194
11	34	57	80	103	126	149	172	195
12	35	58	81	104	127	150	173	196
13	36	59	82	105	128	151	174	197
14	37	60	83	106	129	152	175	198
15	38	61	84	107	130	153	176	199
16	39	62	85	108	131	154	177	200
17	40	63	86	109	132	155	178	201
18	41	64	87	110	133	156	179	202
19	42	65	88	111	134	157	180	203
20	43	66	89	112	135	158	181	204
21	44	67	90	113	136	159	182	205
22	45	68	91	114	137	160	183	206
23	46	69	92	115	138	161	184	207

New Products and Ind. Literature

208	214	220	226	232	238	244	250	256
209	215	221	227	233	239	245	251	257
210	216	222	228	234	240	246	252	258
211	217	223	229	235	241	247	253	259
212	218	224	230	236	242	248	254	260
213	219	225	231	237	243	249	255	261

Books

262	264	266	268	270	272	274	276	278
263	265	267	269	271	273	275	277	279

Progress in Industry

280	282	284	286	288	290	292	294	296
281	283	285	287	289	291	293	295	297

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5	28	51	74	97	120	143	166	189
6	29	52	75	98	121	144	167	190
7	30	53	76	99	122	145	168	191
8	31	54	77	100	123	146	169	192
9	32	55	78	101	124	147	170	193
10	33	56	79	102	125	148	171	194
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18	41	64	87	110	133	156	179	202
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77–79 Charlotte Street,
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Forged Steel Reinforcement Gas Duct Rings

As machined prior to installation 98″ o/d, 68″ i/d, overall width 24″ (by courtesy of Whessoe Ltd.)

As forged and heat treated 101″ o/d, 65″ i/d, overall width 27″ (by courtesy of Whessoe Ltd.)

As machined prior to installation for 3′ 3″ bore inlet duct and duct erection opening for heat exchangers (by courtesy of International Combustion Group)

For Spherical and
Cylindrical Vessels as supplied for the above
NUCLEAR POWER PLANTS

Material B.S.1503/151—1950, grade B, having excellent welding properties, with Charpy V notch impact results of 25 ft. lbs. average at − 10°C.

The Darlington Forge Ltd DARLINGTON

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interested in Pure metals?

chromium — four purity grades available—all over 99.0% pure

niobium — available as beads, roundels, electrodes and ingots

silicon — seven purity grades available—all over 98.0%

tantalum — available as roundels, dendrites, electrodes and many wrought shapes

vanadium — powder at 99.5% purity grade, mill products at higher purity

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Alloys Division

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STEEL CASTINGS FOR PRESSURE/TEMPERATURE INSTALLATIONS AND ELECTRICAL EQUIPMENT USED IN NUCLEAR POWER STATIONS

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The HINDLE H15
Fluon-Seated Leakproof Gate Valve

Illustrated below is a section of this unique valve. Fluon Seats ensure a positive seal on both downstream AND upstream faces

When closed removal of a bonnet bleed plug gives visible proof that the valve is NOT LEAKING

Made in Stainless Steel and Carbon Steel

Covered by British American French and Italian Patents

We will gladly demonstrate this Valve anywhere at any time

JOSHUA HINDLE & SONS LIMITED
Hindle House, Leeds 1. Phone Leeds 30567 (4 lines)
LONDON OFFICE:
157 Prince's Gardens, Acton W3. Phone ACOrn 2471

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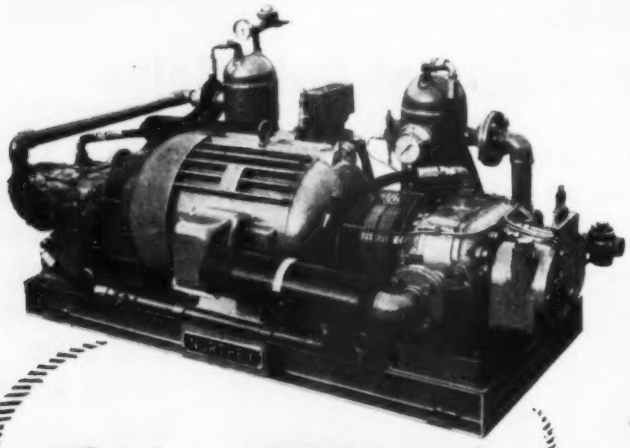

Northey
ROTARY COMPRESSORS LTD

Northey Positive Rotary Compressors and Vacuum Pumps are Precision made machines with a unique "OIL FREE" feature resulting in their ability to deliver air or gas UNCONTAMINATED BY OIL AND OIL VAPOUR. Simple, robust and reliable, Northey machines have been, or are being supplied to the U.K. Atomic Energy Authority at Aldermaston, Dounreay, Harwell, Capenhurst, Springfields and Winfrith.

"OIL-FREE"

COMPRESSORS AND VACUUM PUMPS

Write for details of this highly successful and widely used equipment suitable for gauge pressures up to 65 lbs./sq. in. and vacua to within ½mmHg Abs.

We are prepared to give consideration to the design, development and manufacture of special machines, even on a "one off" basis.

ALDER ROAD · PARKSTONE · POOLE · DORSET

TELEPHONE PARKSTONE 4900 (2 LINES)

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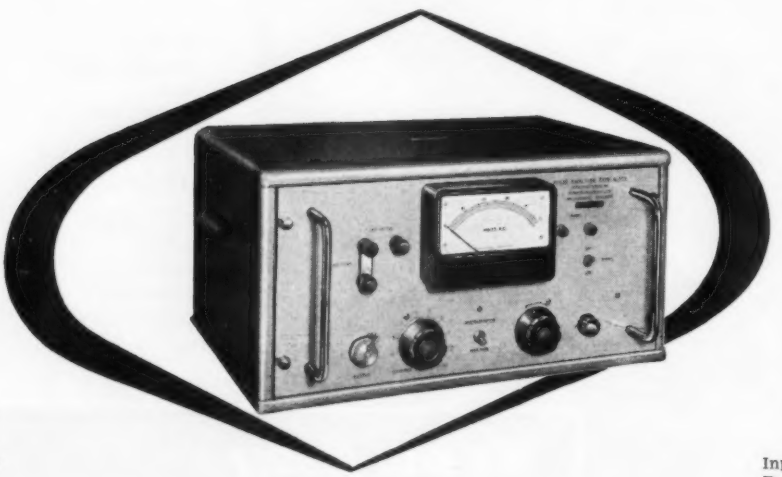

DYNATRON flexible single channel PULSE ANALYSER

Type N 101

SPECIFICATION

Input Pulse : ... ... Positive
Pulse Duration : Minimum 0.2μs (with delay line clipping). 0.4μs (with RC clipping). Minimum 1000μs.
Amplitude : Range of measurement 5-50v (can be extended by extra bias supply connected to terminals on front panel).
Paralysis Level : 100 volt above bias setting
Output Pulse ... ... Positive Amplitude on open circuit 20 volt ; with 100 ohm load, 4v. Length 0.7μs.
Overall Dead Time ... ... Less than 1μs.
Channel Widths : ¼, 1, 1¼, 2, 3, 5, 7½v. selected by a switch.
Accuracy ± 2%. Stability ± 1%.
Accuracy ... ... Pulse height ± 2%

DYNATRON

Ideal for measuring the amplitude of voltage pulses in nuclear laboratories. It transmits only pulses with amplitudes inside a pre-selected voltage range. Seven channel widths are available.

Write for further details of this and other Dynatron instruments.

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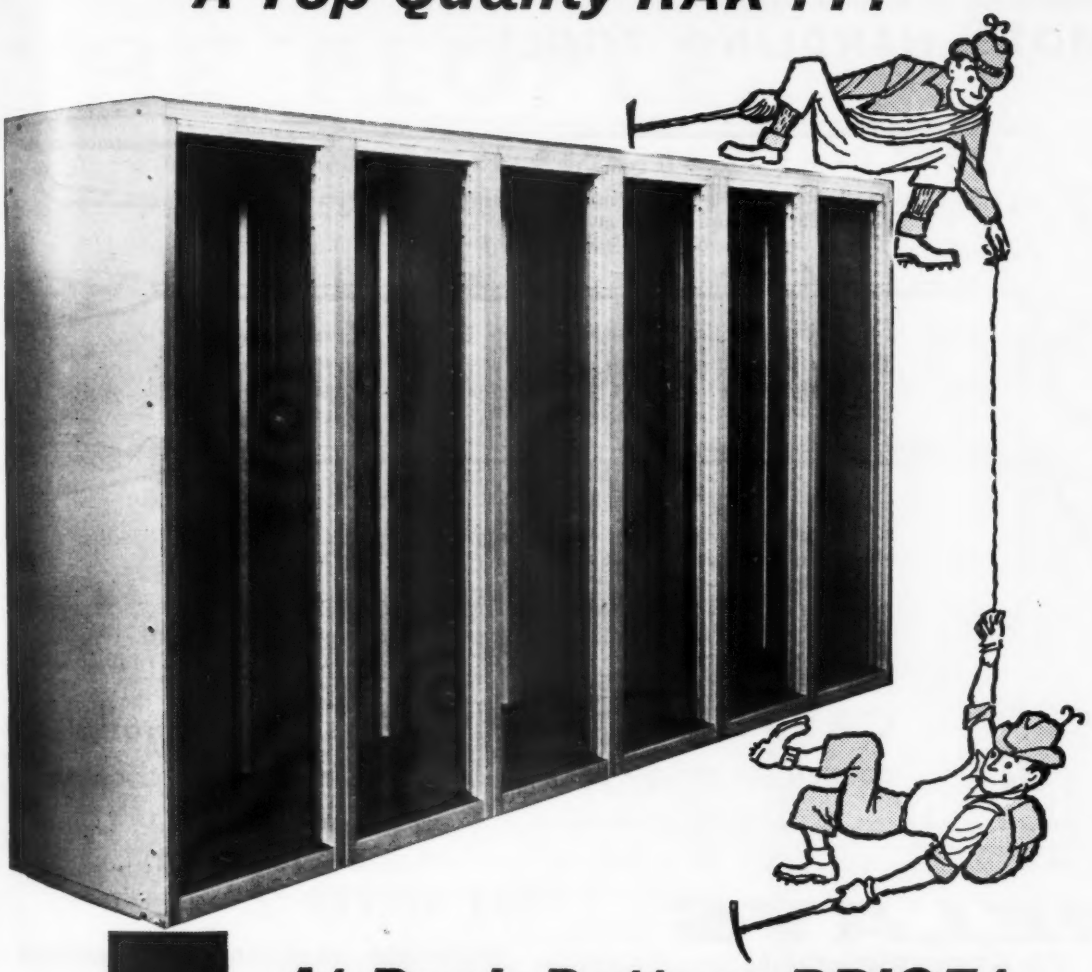
Scalers · Pulse Analysers · Power Units · Probe Units · Pulse Amplifiers · Instrument Racks

A Top Quality RAK . . .



IMRAK

At Rock Bottom PRICE!

6 feet Multi-Bay IMRAK at £27.1.8 per bay. *And* there is a Quantity Discount reduction to £25.9.2 each by the 100.

Complete six-bay rak as illustrated with hinged and quick release rear doors and detachable side panels—only £169.0.11. Fitted with strong yet elegant side doors on 'lift-off' concealed hinges—£174.18.3.

IMHOFS

Imhofs new Imrak International Rak is a completely universal flexible rack system. It can carry British, American and Continental fixings. It packs flat for easy storage or transportation. There are five standard types, each made in four different heights and four different plan sizes—a choice of 80 different standard racks in this new series! There is a choice of normal front panels, one piece front panel or recessed front panels with removable door. Skilful design ensures an elegance of appearance that enhances but does not dominate the instruments. The standard hammertone finishes are ideal for reliability and long service; other finishes are available to special order.

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London Showroom: 112-116 New Oxford Street London WC1 MUSeum 7878

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Algeria: E.G.E.E. Paris (19)
Australia: Aladdin Industries (Pty) Ltd, Stanmore NSW
Belgium: Rogelec, Ghent
Canada: Measurement Engineering Ltd, Arnprior
Denmark: Tage Schouboe, Copenhagen N
Finland: Oy Scienta Ab, Helsinki
France: E.G.E.E. Paris (19)
Germany: Sunvic Regler GMBH Solingen—Ohligs
Holland: J. Th. van Reijsen, Delft
Italy: Stuart Culley, Milan
Mexico: Aluminio Arquitectonico S.A. Mexico D.F.
Morocco: E.G.E.E. Paris (19)
New Zealand: Imarex Ltd, Auckland C3
Norway: Birger Christensen, Oslo
Portugal: Projectos e Construcoes Lda. Lisbon
South Africa: Switchcraft (Pty) Limited, Johannesburg
Sweden: Electronlund AB, Malmo C
Switzerland: Walter Blum, Zurich 2/39
Tunisia: E.G.E.E. Paris (19)
U.S.A.: Bud Radio Inc, Cleveland 3, Ohio
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M

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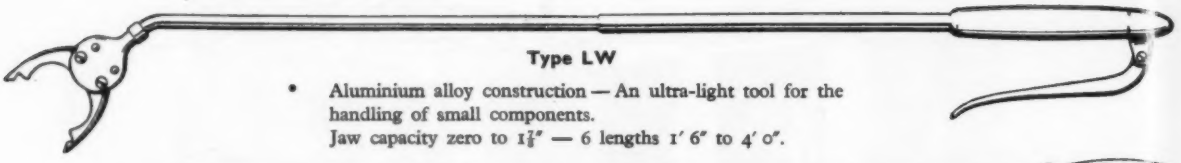
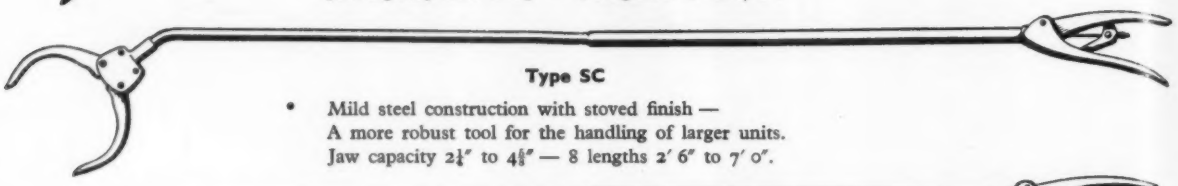
REMOTE HANDLING TOOLS



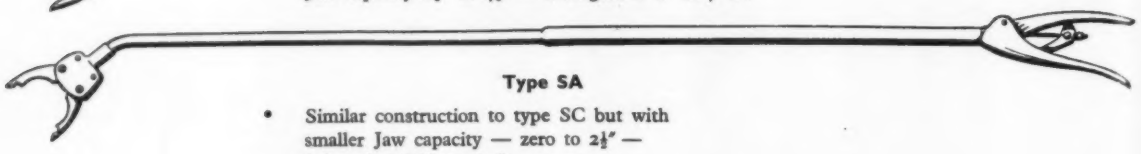
Type LW

- Aluminium alloy construction — An ultra-light tool for the handling of small components.
  Jaw capacity zero to $1\frac{7}{8}$″ — 6 lengths 1′ 6″ to 4′ 0″.



Type SC

- Mild steel construction with stoved finish —
  A more robust tool for the handling of larger units.
  Jaw capacity $2\frac{1}{4}$″ to $4\frac{5}{8}$″ — 8 lengths 2′ 6″ to 7′ 0″.



Type SA

- Similar construction to type SC but with smaller Jaw capacity — zero to $2\frac{1}{2}$″ — 8 lengths 2′ 6″ to 7′ 0″.
- Types SA and SC manufactured in other lengths to order.

Write for details of our range — or let us know your special requirements

CARTER & VINER · PRESS TOOL ENGINEERS

COODEN SEA ROAD · BEXHILL · SUSSEX · TELEPHONE: COODEN 143

Export enquiries to: — C. Phillips Jones & Co Ltd · Dorchester-on-Thames · Oxford

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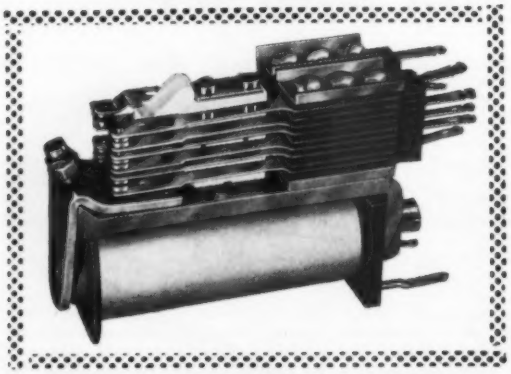
RELAYS
TO SPECIFICATION



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3,000 and 600 RELAYS

Specialists in tropical and Services jungle finish.
Guaranteed to full A.I.D. and I.E.M.E. standards.
Prompt Deliveries Prototypes within 24 hours.
Post Office approved. All relays guaranteed made in our own works.
P.T.F.E. insulation now available.

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TEST SIEVES *for*
accurate particle size analysis

Complete range of all sizes of standard tests sieves conforming to B.S.410:1943 and to U.S. standards, A.S.T.M. Ell, readily available. Also special, non-standard test sieves with stainless steel frames and meshes or with nylon meshes.

Frames fitted with precision woven and uniformly taut meshes. One piece frame and spun fillet construction eliminates crevices between frame and mesh where particles could lodge. Made to nest one with another and to present a perfectly smooth inner surface to the particles of material under test.

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Write or telephone Crawley 25166 for List SV3211

THE PASCALL ENGINEERING CO LTD
GATWICK ROAD · CRAWLEY · SUSSEX

THE PEOPLE

FOR THE COMPLETE PACKAGE DEAL IN SPECIAL PURPOSE EQUIPMENT FOR THE NUCLEAR INDUSTRY

ARE *EVANS* OF PORTSMOUTH

EVANS are justly proud of the part they are playing in the development of Britain's nuclear power.

EVANS have been entrusted with the design, manufacture and installation of the:—

remotely controlled fuel element destrutting and definning machines, remotely controlled fuel element and crate extraction manipulators, the manufacture and supply of the fuel element channel gag and control rod channel gag assemblies for **THE BERKELEY NUCLEAR POWER STATION.**

ALSO the design, manufacture and installation of the:—

remotely controlled skip transfer machines, spent fuel element splitter removal machines, spent fuel element manipulators for **THE HINKLEY POINT NUCLEAR POWER STATION.**

ALSO the design and manufacture of the:—

remotely controlled hydraulic lifting mechanisms for the reactor servicing machines and allied equipment for the **HUNTERSTON NUCLEAR POWER STATION.**

J. EVANS & SON (PORTSMOUTH) LTD.
Marcyn Works, Goldsmith Avenue, Portsmouth, England
Telephone: 32233/6 Grams & Cables: Marcyn Portsmouth

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testing the future

CONTROLLED VIBRATION

Full scale testing is often expensive, though ultimately necessary, yet it is possible to assimilate the conditions under which parts will work by inducing controlled vibration and modifications can then be carried out in the design stage.

In this field, W. Bryan Savage Ltd. have been actively engaged for the past twenty years and are one of the leaders in the manufacture of Power Amplifiers and Vibrators.

W. BRYAN

SAVAGE

LTD

designers and manufacturers of vibrators and amplifiers for modern industry

17, Stratton Street, London, W.1. Phone: Grosvenor 1926

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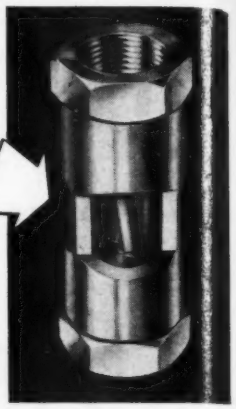
See the flow with the 'Telicator'



Both low and high pressure systems can be fitted with a Telicator Visual Flow Indicator, which is a simple instrument for indicating the flow, whatever the viscosity. The rotors are specially designed by Dukes and Briggs to give the clearest indications over specific ranges of flow rate. Water supplies for cooling purposes and forced lubrication systems are two typical applications. A new model is under development for use with opaque fluids, and special designs can be made to meet specific requirements.

Note these features

- *Simple design ensures complete reliability.*
- *Extreme sensitivity at all pressures.*
- *Units readily adaptable to existing installations.*
- *May be mounted in any plane.*
- *Comparative flow gauged by speed of revolving rotor.*

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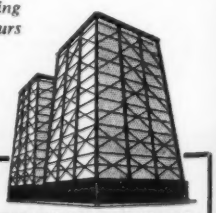
When Cooling's a Problem . . .

Undoubtedly the answer to all air and hydrogen cooling problems is PREMIER. PREMIER closed circuit coolers are among the most highly efficient and economical in the world—installed in such important power stations as Meaford, Poole, Uskmouth, Hams Hall "C", Darlington, Bold "B", Stockport and Johannesburg; and hydrogen coolers and heat exchangers in hand for Hunterston Atomic Power Station and many other overseas works and power stations, large and small.

PREMIER design and erect the plants, guarantee the performance and give a 100 per cent. after-sales service. Certainly, the scientifically engineered construction, high efficiency and economy of PREMIER closed circuit air coolers are the reasons why they are acclaimed by engineers everywhere.

If you have an air or hydrogen cooling problem, write to us—our advice is yours for the asking.

WE *do the designing ourselves.*
WE *manufacture our own plants.*
WE *erect the plants ourselves.*
WE *guarantee the performance.*



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THE PREMIER COOLER & ENGINEERING CO. LTD.
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Small Bore High Pressure Valve for the Dounreay Submarine Project, constructed to satisfy the exacting conditions that will exist in Her Majesty's Submarines to be driven by Atomic Machinery.....

Specially designed and manufactured for delivery to Messrs. Foster Wheeler Ltd. on behalf of the Admiralty, by...

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BOX Nos.:— 1/- extra will be charged

COPY DATE:— Advertisements for December issue to be received not later than November 14th

SITUATIONS VACANT

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Staff are required for the above organisation, which was set up under the Nuclear Installations (Licensing and Insurance) Act, 1959. The duties will include the safety assessment of all proposals for Nuclear Installations and the inspection of such installations during construction, commissioning, and operation. The immediate need is for:—

2 PRINCIPAL INSPECTORS (salary £2,700 (women £2,663) — £3,050); applicants should have 1st or 2nd class Hons. degree in engineering, physics, or mathematics; engineering candidates must also have achieved corporate membership of their professional institution.

7 SENIOR INSPECTORS (salary £1,840 (women £1,809) — £2,120); applicants must normally be at least 37 and have 1st or 2nd class Hons. degree in engineering, physics, or mathematics, or have achieved corporate membership of the appropriate professional institution.

8 INSPECTORS (salary £1,325 (women £1,307) — £1,780); applicants must be at least 30. The qualifications required are the same as for the Senior post.

Applicants without the specified qualifications but with very high scientific or professional attainments may be considered.

Candidates for Principal Inspector posts must have had considerable experience in the nuclear field of managing a team of engineers or scientists, or of industrial management.

Candidates for Senior Inspector or Inspector posts must have had wide experience of responsibility for research, design, operation, or inspection connected with large-scale chemical or engineering plant. Experience in nuclear work is desirable but not essential at this stage, and candidates without this experience will be given the necessary training on appointment.

All the posts are pensionable.

For further particulars and application form apply to Civil Service Commission, 17 North Audley Street, London, W.1, quoting *S/5216/60*. Closing date 10th November, 1960.

SITUATIONS VACANT

PLANNING AND PROGRESS ENGINEER

required by the United Kingdom Atomic Energy Authority, Production Group, Springfields Works, Salwick, Preston, Lancashire, to be responsible to the Senior Planning Engineer for planning and progress of plant overhauls and operation of a comprehensive Planned Maintenance Scheme. Work involves co-ordination of all sections of Works Engineering Department.

A recognised engineering apprenticeship, corporate membership of a senior engineering institution, or equivalent, and experience in planning and progressing of maintenance projects as applied to a large Works, are essential. Familiarity with operation of Planned Preventative Maintenance Schemes is desirable.

Salary: £1370 to £1825 per annum.

Staff Housing Schemes. Contributory Superannuation.

Send postcard for application form, quoting reference SF.74/J.28, to Works Secretary at above address.

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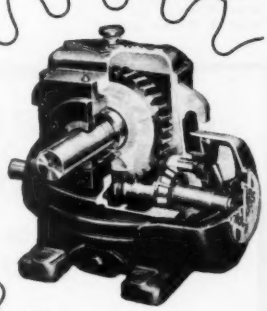

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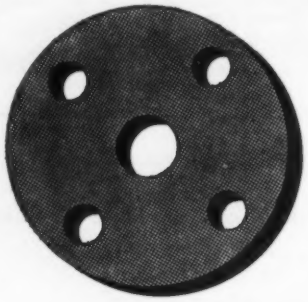

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Nuclear Power Group, The 17

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Two graphite moderated CO_2 cooled and natural uranium fuelled reactors will provide steam for dual-pressure turbo-generators. The cooling water for the Condensers will be drawn from the Trawsfynydd Lake, seen partially filled in the background, and the warmed water returned there for natural surface cooling. Entry to the site was on 1st July, 1959.

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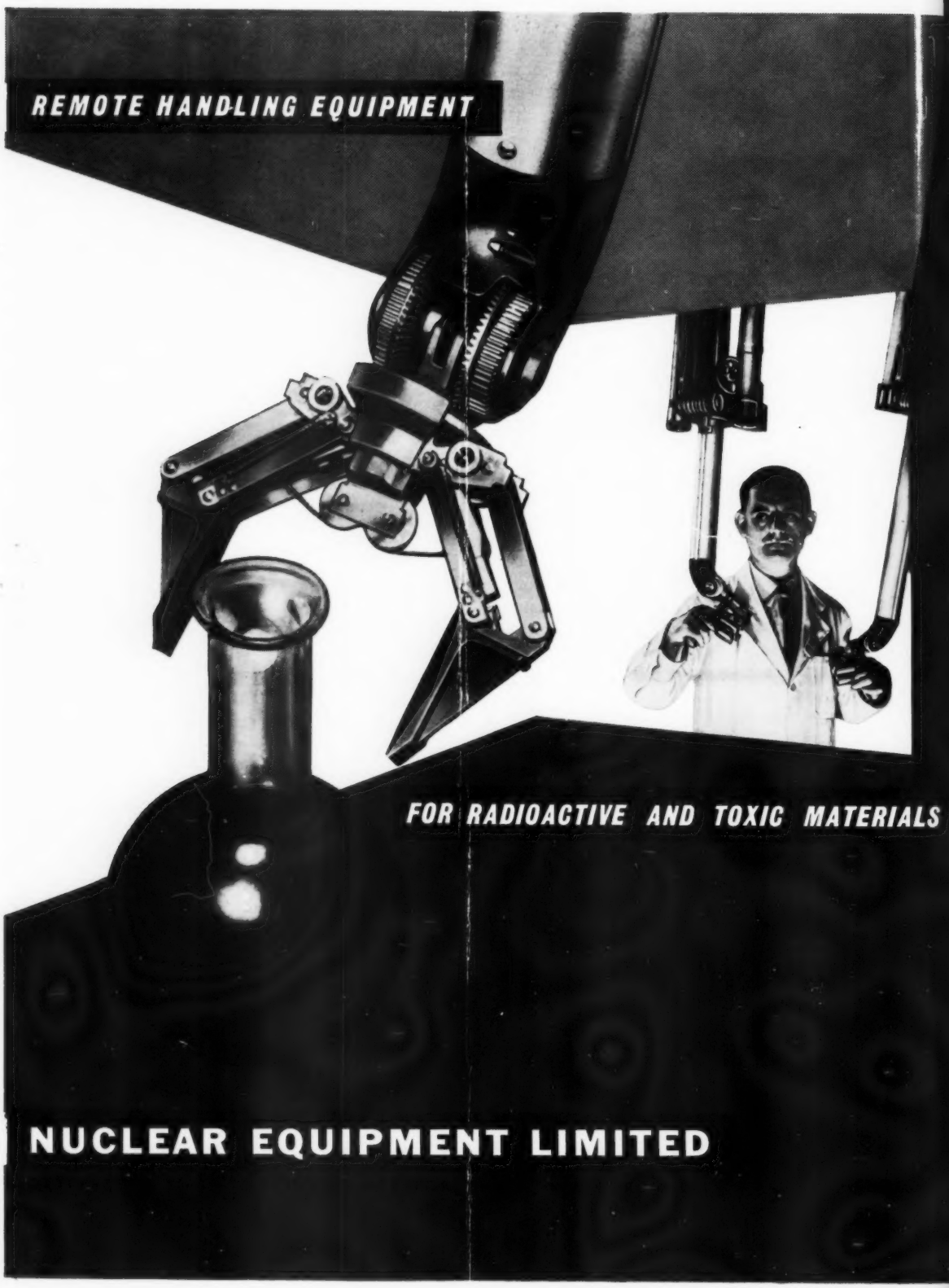

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